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Body Mass Index Trajectories And The Relationship Between Stressful Life Changes And Nutrition-Related Health Outcomes Among United States Army Soldiers

Julianna Marie Jayne
University of South Carolina

BODY MASS INDEX TRAJECTORIES AND THE RELATIONSHIP BETWEEN STRESSFUL LIFE CHANGES AND NUTRITION-RELATED HEALTH OUTCOMES AMONG UNITED STATES ARMY SOLDIERS

by

Julianna Marie Jayne

Bachelor of Science
Winthrop University, 2006

Master of Science
Baylor University, 2008

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Accepted by:

Christine E. Blake, Major Professor

Edward A. Frongillo, Committee Member

Angela D. Liese, Committee Member

Bo Cai, Committee Member

Cheryl L. Addy, Vice Provost and Dean of the Graduate School

PREFACE

The views expressed in this document are those of the author and do not reflect the official policy of the Department of Army, Department of Defense, or the U.S. Government.

DEDICATION

This work is dedicated to my savior, Jesus, to whom I owe every breath and my tremendously blessed life. My husband, Tim, the first person to truly see me. His love, support, and relentless faith sustained me on the hardest days. Our resilient and precious children: Isaac, Ethan, Lilian, Abigail, and Alexandra, who are my most important work and greatest treasure. My parents, Jeff and Janet, who taught me how to serve and whose love, support, and spiritual legacy have been guiding forces in my life. And finally, the men and women who are the American Soldier, their dedication and sacrifice was my inspiration.

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ABSTRACT

Body mass index (BMI) has risen among members of the military, though to a lesser degree than in civilian populations. BMI as an anthropometric tool has been essential for population surveillance and documenting the obesity epidemic and its health consequences. One use for BMI in population surveillance is to model the BMI trajectories of a population over time. Many studies are available on the BMI trajectories and determinants of BMI in civilians, but few studies of this nature in military populations exist. Establishing the shape and determinants of BMI trajectories among Soldiers is critical given the importance of weight management to military service requirements.

Military service can be characterized as an ever-changing, demanding profession that requires dedication to a highly stressful lifestyle. Unites States Army Soldiers must balance stressors that normally occur over an individual's life-course with unique stressors associated with Army service, such as deployment and routine relocations. Soldiers must also meet physical fitness requirements, adhere to body mass index-based body composition standards, and remain free of major physical limitations to remain in service. Despite these requirements, Soldiers are not free of many of the chronic health conditions present in the general population such as obesity and hyperlipidemia.

Stress has been implicated as a contributor to health conditions such as obesity, hypertension, and hyperlipidemia. Soldiers have the same stressful life changes as civilians, including marriage, divorce, childbirth, and job change in addition to unique

stressors related to frequent relocations, being deployed to a combat zone, and reintegrating from deployment. Stressful experiences may change behavior and alter an individual's physiology leading to undesirable health outcomes. Considering that health consequences of chronic stress may impact the ability of Soldiers to meet Army standards or perform their duties, there is a salient need to investigate the impact of stress on Soldier health.

Two specific aims were proposed in this dissertation. Both aims used longitudinal data from the Stanford Military Data Repository representing all active-duty U.S. Army Soldiers who were age 17-62 between 2011 and 2014 (n=827,126). Specific aim 1 was to model the overall BMI trajectory of Soldiers, find the most common trajectory groups among Soldiers, investigate the relationship between BMI trajectories and sociodemographic and military-specific characteristics, and determine if there were Soldiers with large fluctuations in BMI. Group-based trajectory modeling was used to identify the BMI trajectories of Soldiers and multinomial logistic regression was used to estimate associations between Soldier characteristics and trajectory membership. In a smaller sample, person-specific growth curves were used to identify Soldiers with large intra-individual variability, such as BMI fluctuations caused by weight cycling.

Specific aim 2 was to determine if experiencing stressful life changes was associated with blood pressure changes, an earlier onset of hyperlipidemia diagnosis, substantial weight gain, or being separated from the Army for failure to meet body composition standards. A sub-aim was to determine which stressful life changes were most associated with these outcomes and if there were gender differences in the effects. Stressful life changes were marital transitions, deployment to a combat zone, return from deployment, rank change, relocation, change in occupation, and developing a physical limitation to duty. Event history analysis was used to model the association of stressful life changes with study outcomes.

For specific aim 1, four distinct BMI trajectory groups were found: increasing, decreasing, constant, and inconstant. The constant, increasing, and decreasing trajectories were similar in shape and percentage between men and women. The constant trajectory had the fewest Soldiers who exceeded weight standards or had duty limitations. The increasing trajectory was associated with marriage and fewer service years. The decreasing trajectory was associated with more service years and higher educational attainment. The inconstant trajectory differed in shape between men and women. Over 6% of men and 12% of women had fluctuations in BMI indicative of weight cycling. Characteristics of Soldiers, such as service years, age, and limitations to duty were associated with BMI trends.

For specific aim 2, results showed marriage increased odds of substantial weight gain three months later by 1.23 times for men and 1.68 times for women with women having a higher cumulative probability of weight gain in the 12 months following marriage. Relocation was associated with lower blood pressure in men and women, but higher odds of substantial weight gain in women. Developing a physical duty limitation increased odds of hyperlipidemia two months later by 1.42 times for men and 1.83 times for women and the odds of substantial weight gain two months later by 3.16 times in men and 1.68 times in women. Stressful life changes were found to have an effect on nutrition-related health outcomes among Soldiers with differing effects between men and women.

Soldiers in the Army have unique challenges related to service requirements and life experiences resulting from military service. Even though Soldiers are often young and active, they are not free of nutrition-related health concerns such as obesity and hyperlipidemia. Understanding and utilizing Soldier characteristics associated with BMI may assist the Army in targeting resources aimed to improve Soldier health and combat readiness. Identifying times in a Soldiers life-course when the risk of developing an undesirable health outcome is highest could help the Army employ existing resources to help mitigate the stress response and the effects of stress on health.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABCP .... Army Body Composition Program

APFT ....Army Physical Fitness Test

AR ....Army Regulation

BMI ....Body Mass Index

CAPER................................. Comprehensive Ambulatory/Professional Encounter Record

CSF2 .... Comprehensive Soldier and Family Fitness

CVD ....Cardiovascular Disease

DMDC...Defense Manpower Data Center

DoD.. Department of Defense

DTMS ....Digital Training Management System

eProfile..Army system for documenting medical duty limitations

GBTM ....Group Based Trajectory Models

HPA... Hypothalamus-pituitary-adrenal

ICD...International Classification of Diseases

LTHET ....Long Term Health Education and Training

MDR ....Military Health System Data Repository

MNR .... Medically Not Ready

MRAT ....Medical Readiness Assessment Tool

OEF .... Operation Enduring Freedom

OIF ....Operation Iraqi Freedom

PHA..Periodic Health Assessment

RQ .... Research Question

SMDR ....Stanford Military Data Repository

CHAPTER 1

INTRODUCTION

1.1 Health Threats to Army Capabilities

Obesity

The obesity epidemic is a serious public health concern with major implications for organizations such as the United States Army, which has standards for weight and body composition as a condition of entry and retention (Cawley & Maclean, 2012; Hruby et al., 2015). The deleterious health effects of obesity (Ogden, Yanovski, Carroll, & Flegal, 2007) have a direct effect on force readiness (e.g., ability of Soldiers to perform all aspects of military service). These effects include chronic disease, musculoskeletal injuries, lost duty time, and the inability of Soldiers to pass physical fitness tests (Ananthila Anandacoomarasamy, Caterson, Sambrook, Fransen, & March, 2008; Cawley & Maclean, 2012; Ogden et al., 2007; Sanderson, Clemes, & Biddle, 2011; US Army Surgeon General Report, 2015).

Within the active-duty component of the U.S. Army, which employs 475,000 Officers and Enlisted personnel(“National Defense Authorization Act for Fiscal Year 2016,” n.d.), it is estimated that 13-15 percent of Soldiers are obese, based on a body mass index (BMI) of ≥ 30 kg/m^2 (Reyes-Guzman, Bray, Forman-Hoffman, & Williams, 2015; US Army Surgeon General Report, 2015). While obesity rates in the Army are not as high as the general population, the relevance of physical fitness and body composition to Army requirements and force readiness make obesity an urgent issue that the Army

Surgeon General designated as a key health indicator (Cawley & Maclean, 2012; United States Army Surgeon General, 2015b; US Army Surgeon General Report, 2015).

Weight gain

The Army's weight and body composition regulations designed to keep Soldiers from becoming overfat must be inclusive to the variation in body shapes found in a population. To address this challenge, the Army's weight screening tables allow for up to a 23 kilogram range between a Soldier's minimum and maximum allowed weight depending on a Soldier's height and gender (Marriott & Grumstrup-Scott, 1992; United States Army, 2013). Weight screening tables allow for a Soldier's weight to increase with age to a limited degree and allows a Soldier's weight to fluctuate without prompting an intervention or administrative actions (United States Army, 2013). The emphasis in the literature has been on Soldiers who are already overweight or obese, but even moderate weight gain can indicate a Soldier is having difficulty with weight management. Given the threats to readiness that overweight and obesity pose, (Cawley & Maclean, 2012) weight gain is a concern even if it does not immediately cause a Soldier to exceed weight standards because it puts a Soldier closer to exceeding weight standards in the future.

Hypertension and hyperlipidemia

Other threats to the health of Soldiers are chronic diseases or precursors of chronic disease, many of which are related to overweight and obesity. Hypertension and hyperlipidemia threaten a Soldier's ability to perform their duties and be in adherence with regulations. Cardiovascular disease (CVD) is the leading cause of death and disability in the United States with half of all Americans having at least one known risk factor ("Heart Disease Fact Sheet," 2017). Since the Army recruits from the general population, Soldiers are not immune from risk. Studies show that CVD can begin in early adulthood (McMahan et al., 2005) and is present among Soldiers (McGraw, Turner, Stotts, & Dracup, 2011).

Stress

The development of health outcomes that threaten military readiness represents a complex interaction between an individual's physiology, environment, and psychology, all of which are influenced by military service. Military service can be characterized as an ever-changing, demanding profession that requires dedication to a highly stressful lifestyle. Enlisted military service consistently ranks as one of the most stressful professions ("The Most Stressful Jobs of 2018," n.d.). Soldiers must balance the stresses that normally occur over an individual's life-course with unique stressors associated with Army service, such as deployment and routine relocations. Considering that enlisted military personnel have highly stressful jobs and comprise 82% of the Army's total force (371,874 Soldiers) ("Military Careers," n.d.), there is a salient need to investigate the impact of stress on Soldier health.

1.2. Gaps in knowledge

BMI trajectories of Soldiers

BMI as an anthropometric measure has been important for population surveillance, and was essential in establishing the obesity epidemic and its health consequences (Prentice & Jebb, 2001). One use for BMI in population surveillance is to model the BMI trajectories of a population over time (Heo et al., 2003). Many studies are available on BMI trajectories of adults, children, and some specialized populations, (Timothy J. Cole, Freeman, & Preece, 1995; de Groot et al., 2014; Jackson, Janssen, Sui, Church, & Blair, 2012a; Tu, Mâsse, Lear, Gotay, & Richardson, 2015; Walsemann, Ailshire, Bell, & Frongillo, 2012) but few longitudinal studies of BMI trajectories in military populations exist. Military-specific characteristics such as duty limitations, rank, or branch of Army may be associated with BMI, but relative little research is available on the sociodemographic or military-specific characteristics associated with BMI (T. J. Smith et al., 2012) or longitudinal BMI trends among Soldiers (Hruby et al., 2015; Reyes-Guzman et al., 2015). Examining how Soldier characteristics relate to BMI trends may inform future research aimed at increasing compliance with weight standards and corresponds with Army priorities of improving combat readiness (*Army Medicine Campaign Plan*, 2017).

Stressful life changes and nutrition-related health outcomes

Soldiers must meet physical fitness requirements, be in compliance with weight and body composition standards, and remain free of major physical limitations to remain in service (United States Army, 2013; United States Army, 2016b). Stress is a contributor to health conditions such as obesity, hypertension, and hyperlipidemia (Black, 2003; Kivimäki et al., 2002; Lagraauw, Kuiper, & Bot, 2015; Stoney, Bausserman, Niaura, Marcus, & Flynn, 1999; Stoney, Niaura, Bausserman, & Matacin, 1999). The negative health consequences of chronic stress may impact the ability of Soldiers to maintain Army requirements, (Hammen, 2005; Krantz, Grunberg, & Baum, 1985; Lydeard & Jones, 1989) but there is little research on the associations between stressful life changes and nutrition-related health outcomes among Soldiers (Granado et al., 2009).

1.3 Research Objectives and Aims

The main objectives of this research was to address gaps in knowledge about the shape and determinants of BMI trajectories and the associations between stress and specific nutrition-related health outcomes in Soldiers. This research was guided by a conceptual model that links stressful life changes to the development of nutrition-related health outcomes of interest to the Army. Underpinning the conceptualization of the dynamic process of how stressful changes affect health is the life-course perspective, which is a theoretical framework for examining how life changes influence future health. Life-course constructs of transitions, adaptive strategies, and timing support the discourse between stressful life changes and nutrition-related health outcomes.

Specific Aim 1: To model the BMI trajectories of active-duty U.S. Army Soldiers.

RQ1: What is the overall BMI trajectory of the Army and does it differ from the overall BMI trajectory of the general population?

RQ2: What are the most common BMI trajectory groups among Soldiers?

RQ3: Are select sociodemographic and military-specific characteristics associated with BMI trajectory groups of Soldiers?

RQ4: Are there Soldiers with large fluctuations in BMI that would not be identified in group trajectory models?

RQ5: Are there differences between men and women in the shape or determinants of BMI trajectories?

Based on this author's experience as an Army dietitian, knowledge of Army requirements, and a review of the literature, it was hypothesized there would be (1) substantive differences between the BMI trajectory of Soldiers and BMI trajectories of civilians observed in other studies, (Jackson et al., 2012a; National Center for Health Statistics (U.S.) & National Health and Nutrition Examination Survey (U.S.), 2016) (2) there would be would be at least three distinct BMI trajectories, a majority group with a constant BMI, those who gained BMI, and those with an inconstant BMI, (3) that that certain Soldier characteristics would be associated with BMI trajectory, (4) that BMI fluctuations would be common, and (5) that men women would differ in determinants and shape of BMI trajectories.

Specific Aim 2: To identify and model the stressful life changes that have the greatest association with substantial weight gain, separation for failure to meet body composition standards, and specific cardiovascular risk factors over time.

RQ6: Is experiencing stressful life changes associated with a change in blood pressure, an earlier onset of hyperlipidemia diagnosis, substantial weight gain, or being separated from the Army for failure to meet body composition standards?

RQ7: Which stressful life changes are most associated with these outcomes?

RQ8: Are there differences in effects between men and women?

It was hypothesized the analysis would show that for the outcomes of hyperlipidemia and substantial weight gain, the most stressful life changes would be marital transitions, relocation, and becoming medically not ready (MNR) and that the magnitude of the associations would be different in men and women (Spruill, 2010).

1.4. Justification

The Army is working towards a proactive approach to Soldier health ("Total Force Fitness," n.d.). Spurred by the rising cost of healthcare and prevalence of obesity and other health threats among the force, the Army is investing heavily in programs aimed at improving the health of Soldiers and understanding the factors contributing to health outcomes that compromise a Soldier's ability to perform their duties (Lentino, Purvis, Murphy, & Deuster, 2013; Purvis, Lentino, Jackson, Murphy, & Deuster, 2013; "Total Force Fitness," n.d.; United States Army Surgeon General, 2015b). By using a theory-based approach and longitudinal data that encompasses the entire active-duty Army population, this research represents a novel approach to the examination of these outcomes. These findings are useful to the Army medical command and supports Army medicine's goal of optimizing Soldiers' medical readiness (United States Army Surgeon General, 2015b; United States Army Surgeon General, 2015a).

1.5. Overview

In addition to this introductory chapter, chapter 2 of this dissertation provides detail on the background and significance of issues surrounding BMI, BMI trends, stress, and nutrition-related health outcomes as they relate to the Army and explains the conceptual framework underpinning this research. Chapter 3 will describe the methodology used to answer the research questions. Chapter 4 presents the results conveyed in the form of two distinct manuscripts. Chapter 5 provides a summary of the findings and how implications of this research contributes knowledge to the field and identifies areas of future research.

CHAPTER 2

BACKGROUND AND SIGNIFICANCE

This chapter will provide detail on how BMI trajectories have been used in population surveillance as well as how this research provides useful information to the Army. Details on the implications of obesity and stress on Soldier health is included in this chapter as well as key historical information on the origins of stress research along with an explanation of how stress influences health using both recent and benchmark studies. A discussion of the stressful life changes used in this research is presented. The theory and conceptual framework this research is based on is also explained in this chapter.

2.1 Usefulness of BMI and BMI Trajectories in Population Surveillance

Anthropometry is used for gathering information on weight and weight changes among populations. As the prevalence of overweight and obesity has risen, BMI has become the most common index of weight status in obesity literature, largely due to its association with mortality and its ease of measurement (Flegal & Troiano, 2000; Jackson et al., 2012a; *Physical Status: The Use and Interpretation of Anthropometry: Report of a WHO Expert Committee*, 1995). BMI as an anthropometric tool has been essential for population surveillance, and played a key role in establishing the obesity epidemic and its health consequences (Prentice & Jebb, 2001). BMI has long been used as a measure of relative weight and to define obesity (Flegal & Troiano, 2000; Jackson et al., 2012a). Critiques of BMI often refer to examples demonstrating BMI as a poor measure of body fatness especially in those with high or low lean mass, such as athletic or disabled persons, but its correlation to percent body fat in large populations makes it useful for tracking population weight trends (Flegal et al., 2009; Flegal, Kruszon-Moran, Carroll, Fryar, & Ogden, 2016; Seidell & Flegal, 1997).

Tracking BMI trends among populations is critical for determining when BMI changes occur and to what degree changes are due to secular trends, age, or other factors (Timothy J. Cole et al., 1995; T.J. Cole, 2003). In studies examining BMI trends in the United States, the literature points to two separate trends (1) prevalence of obesity has steadily increased over the last 30 years, (Flegal et al., 2016; Flegal & Troiano, 2000) and (2) obesity increases with age (Jackson et al., 2012a; Ogden, Fryar, Carroll, & Flegal, 2004).

Since 1980, the prevalence of obesity, defined as a BMI of $\geq$30 kg/m^2, has increased in the United States, although not at identical rates for all groups (Flegal, Carroll, Kit, & Ogden, 2012). As of 2014, the prevalence of obesity in the United States was 35% among men and 40% among women (Flegal et al., 2016). Compared to 2008, this reflects a significant change for women, but not for men (Flegal et al., 2012, 2016). While prevalence for men has not increased in the last 6-8 years, obesity rates remain alarmingly high despite widespread public concern over the health effects of obesity (Flegal et al., 2016). Both ends of the BMI spectrum pose health risks, although the focus is typically on obesity due to the larger number of individuals at the higher end of the BMI spectrum and due to the cultural value of thinness in American society (Troiano, Frongillo, Sobal, & Levitsky, 1996).

Changes in body composition, including increases in BMI, appear to be part of the aging process and reflect societal trends of excessive energy intake and sedentary lifestyles (Kyle, Genton, Slosman, & Pichard, 2001). In a large, longitudinal study on men ages 20-96, BMI, fat mass, and body fat percent increased with age, leveling off at 70 years of age (Jackson et al., 2012a). Another study in both men and women found that fat mass increased until 75 years of age, stabilizing thereafter (Kyle, Genton, Hans, et al., 2001). A large body of research supports this trend in both men and women (Kyle, Genton, Slosman, et al., 2001; Rissanen, Heliövaara, & Aromaa, 1988; Williamson, Kahn, Remington, & Anda, 1990).

While many studies have examined body composition changes in older adults, pediatrics, or specialized populations, this author could locate few studies of this nature in a military population. The military has unique characteristics based on combat exposure, physical demands, and an environment that emphasizes weight management. In one study examining trends in overweight among active-duty military members, overweight increased despite increases in physical activity in the same time period (Lindquist & Bray, 2001). Other studies on veterans mirror civilian population BMI trends and show that increasing age is associated with an increase in BMI (Rosenberger, Ning, Brandt, Allore, & Haskell, 2011).

Some studies have examined BMI trends by using BMI trajectories to show the “natural growth curves” in a population over time (Heo et al., 2003). When examining trends in BMI, longitudinal data enables researchers to answer questions that incorporate time as a factor, which is essential for establishing temporal sequence and causation (Frongillo & Rowe, 1999; Heo et al., 2003). Using longitudinal data to model the BMI trajectories of Soldiers enables the overall and common BMI trajectories that characterize the Army population to be established and identifies the sociodemographic military-specific characteristics associated with BMI.

2.2 Implications of Obesity for the Army

For organizations such as the Army that have physical fitness requirements, weight and body composition standards, and requirements for Soldiers to be essentially healthy for service and retention, threats to the health of Soldiers are a major concern (United States Army Surgeon General, 2015b). The obesity epidemic poses a serious threat to the Army. By reducing the number of available candidates for service and increasing the likelihood that existing service members will become obese, the obesity epidemic has been called a threat to national security ("Obesity Epidemic a Threat to U.S. Military Personnel and National Security," n.d.). It is estimated that 31% of young adults eligible for military service are disqualified for service due to overweight or obesity (Bornstein et al., 2018; Center for Disease Control, n.d.). For those who do qualify and volunteer for military service, nearly 50% of new recruits fail physical fitness tests in basic training (Bornstein et al., 2018). Those who meet entrance standards but become overweight or obese while in service are more likely to be involuntarily separated or receive a medical discharge ("Duration of service after overweight-related diagnoses, active component, U.S. Armed Forces, 1998-2010," 2011; Packnett, Niebuhr, Bedno, & Cowan, 2011). Overweight or obese service members utilize more healthcare dollars and have greater absenteeism (Dall et al., 2007). Obese Soldiers are less likely to be able to deploy to a combat zone, which directly impacts the Army's ability to perform its primary mission (Center for Disease Control, n.d.; Dall et al., 2007).

2.3 Implications of Stress on Health

The development of undesirable health outcomes occurs through biological and environmental paths including those that are influenced by stress (Galea, Riddle, & Kaplan, 2010). The concept of "stress" can have different meanings. For purposes here, stress is defined as the process in which "environmental demands tax or exceed adaptive capacity…resulting in psychobiological and biological changes that may place persons at risk for disease" (S. Cohen, Kessler, & Gordon, 1995; Spruill, 2010). Exposures that can tax the adaptive capacity of individuals are stressful life changes (Dohrenwend, Askenasy, Krasnoff, & Dohrenwend, 1978; Sarason, Johnson, & Siegel, 1978) that produce a physiological stress responses and require adaptations in behavior that can affect disease risk (Peggy A. Thoits, 1983). Examples of stressful life changes include divorce, relocation, changing jobs, or illness, (Dohrenwend et al., 1978; Sarason et al., 1978) but even life changes that are typically viewed as desirable, such as marriage or the birth of a child, can be stressful due to individual circumstances and the adaptations required to meet the challenges of changing roles and responsibilities (Dohrenwend & Dohrenwend, 1974; Kaplan, 1983; Sarason et al., 1978). While no life change can be classified as "universally stressful" to all individuals, (Cassel, 1976; Krantz et al., 1985) some life changes are more likely to tax the adaptive capacity of individuals, particularly when changes are clustered, chronic, and complex (Abood & Milton, 1988; Dohrenwend et al., 1978; Dohrenwend & Dohrenwend, 1974; Hammen, 2005; Holmes & Rahe, 1967; Johnston & Wallace, 1990; Rosch, 1979; Sarason et al., 1978; Steptoe, 1991; Peggy A. Thoits, 1983).

2.4 Origins of Stressful Life Changes/Events Research

Termed stressful life events or stressful life changes, the foundations of stressful life events research can be attributed to W.B Cannon (1929), who proposed that illness could result from "emotion provoking stimuli;" Adolf Meyer (1951), who taught physicians to use life event questionnaires to help understand disease etiology; and Hans Selye (1956), who proposed that the physiological stress response includes alarm, resistance, and exhaustion – which could result in disease (Dohrenwend & Dohrenwend, 1974; Kaplan, 1983). After World War II, stressful life events research was highly influenced by psychiatric studies of Soldiers' response to combat exposure and studies on the impact of traumatic events (Kaplan, 1983). The growing body of research also started moving towards examining the impact of life changes that encompass stress but to a lesser degree than traumatic events. Holmes and Rahe's creation of the Social Readjustment Rating Scale (SRRS) (1967) was the first of its kind to associate life changes with the onset of illness (Holmes & Rahe, 1967). Holmes and Rahe created the SRRS using U.S. Navy medical records to derive a list of events that preceded illness; the list was then rated by civilian volunteers to establish the level of "readjustment" the life event would require (Kaplan, 1983).

Since the creation of the SRRS and other similar life event scales, critiques of the methodology have identified issues with scales that assign a weight to each life event, but do not take into account individual perception of event magnitude (Dohrenwend et al., 1978). These critiques led to the creation of scales where life events were nominated by samples from the general population, such as the Peri Life Events Scale (Dohrenwend et al., 1978) and the Life Experiences Survey (Sarason et al., 1978). While no stressful life events scale is a perfect measurement tool, in the more than 50 years since life events research originated, this much is clear: There is a significant association between stressful life changes and health, particularly when events are clustered (Abood & Milton, 1988; Dohrenwend & Dohrenwend, 1974; Hammen, 2005; Holmes & Rahe, 1967; Johnston & Wallace, 1990; Kaplan, 1983; Rosch, 1979; Sarason et al., 1978; Steptoe, 1991; Peggy A. Thoits, 1983).

2.5 Stressful Life Changes and Army Life

This research examined the relationship between nutrition-related health outcomes and the following stressful life changes: marital transitions, deployment and returning from deployment, relocation, birth/adoption of a child, rank change, occupation change, and developing a physical duty limitation. With the exception of deployment, all stressful life changes used in the proposed research match those found in two well-known life event measures: The Life Experiences Survey (Sarason et al., 1978) and the PERI Life Events Scale (Dohrenwend et al., 1978).

Enlisted military service consistently ranks as one of the most stressful professions based on criteria such as workplace hazards, physical demands, deadlines, and environmental conditions ("The Most Stressful Jobs Of 2015," n.d.; "The Most Stressful Jobs of 2016," n.d.). This assessment is consistent with the 15 years of sustained wartime operations that have involved more Army service members than any other military branch (Bonds, Baiocchi, & McDonald, 2010). The Army has supplied more than 50 percent of all troops deployed in support of Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF); (Bonds et al., 2010) and as of December 2011, over 70 percent of active-duty Soldiers had deployed one or more times in support of

OIF/OEF (Bonds et al., 2010). Multiple studies have linked combat exposure to increased risk of morbidity and mortality, (Chatterjee, Spiro, King, King, & Davison, 2009; Elder, Clipp, Brown, Martin, & Friedman, 2009; Schnurr, Spiro, Aldwin, & Stukel, 1998) but deployments are just one example of stress as a fundamental characteristic of military service.

Even for military members who were not combat exposed, the "social disruption" that service members experience as a result of military service can have health impacts throughout their lives (Elder et al., 2009). Social disruption describes the "disrupted lives, uncertainty, and challenges" of military life (Elder et al., 2009). One way Soldiers experience social disruption is the frequent relocations that require Soldiers and their families to generate new social support networks. Relocations typically stabilize after initial training periods, with the average relocation occurring every 24 to 36 months, (Burrell, 2006) but routine relocations make establishing social support networks extremely challenging for both Soldiers and their families, and is one of the top concerns of military spouses (Burrell, 2006).

Soldiers experience the same stressful life changes such as marriage, divorce, childbirth, and job change as civilians, but in the context of Army life. In today's military, more than 60 percent of Soldiers have at least one dependent and it is far more likely for Soldiers to be married, have children, and have working spouses than in the past (Drummet, Colemann, & Cable, 2003; Moelker, Andres, Bowen, & Manigart, 2015). These shifts in demographics require Soldiers to balance the demands of two "greedy institutions" – the family and the military – that demand "exclusive and undivided loyalty" (Segal, 1986). Service members bear the same responsibilities for child care, education, parenting, and career management, while undergoing unique military stressors such as relocation, short-term family separations, lengthy deployments, and reintegration when they return (Drummet et al., 2003). These tensions can be particularly difficult for female service members as they work to balance the demands of motherhood and their military careers (Wahl & Randall, 1996). These factors must be balanced and managed on a continual basis and act as an important contextual factor when considering how Soldiers respond to stressful life changes.

Soldiers cannot deploy to combat zones are classified as medically not ready (MNR) for deployment. Soldiers can become MNR for a variety of reasons including mental health issues, physical injury, or illness. According to an Army Surgeon General report, in 2015, 17% of the active-duty force was classified as MNR, which limits the ability of units to deploy (US Army Surgeon General Report, 2015). Ability to deploy is a key requirement of a ready, fighting force. MNR Soldiers represent a portion of the active-duty population with the greatest limitations to duty and are a "significant problem" for unit readiness (US Army Surgeon General Report, 2015).

For Soldiers, becoming MNR can represent a significant change with career ramifications. Soldiers are evaluated annually for promotion or retention and physical fitness is a component of both Officer and Enlisted evaluations. Soldiers are physically active and rigorous physical training can lead to injury, (B. H. Jones et al., 1993) with musculoskeletal injuries representing one of the top reasons for injury and disability in the Army (A. D. Nelson & Kurina, 2013). Becoming MNR can limit a Soldiers ability to perform job-related duties of a physical nature (United States Army, 2016b). Illness and injury has been shown to have a detrimental impact on a person's identity (R. T. Smith &

True, 2014) and for Soldiers who develop a physical limitation to duty, their identity as a Soldier is threatened. For these reasons, becoming MNR was considered a stressful life change in this research.

2.6 Appraisal and Stressor Characteristics

The degree to which stressful life changes influence health is largely based on the characteristics of the stressor and how it is perceived by the individual (Dohrenwend & Dohrenwend, 1974; Kaplan, 1983; Tomaka & Blascovich, 1994). How an individual appraises the severity of a life event along with the characteristics of the stressor, such as its complexity, controllability, and intensity, will affect how a person responds to the event (Steptoe, 1991; Peggy A. Thoits, 1983; Tomaka & Blascovich, 1994). The appraisal process, which is how an individual "categorizes an encounter and its various facets, with respect to its significance for well-being" (Tomaka & Blascovich, 1994) is greatly influenced by individual and social factors such as personality characteristics, coping styles and strategies, external resources, and social support.

Individual personality traits influence how stress is perceived (Johnston & Wallace, 1990). Components of personality such as hardiness and optimism influence appraisal and promote a lower stress response (Lecic-Tosevski, Vukovic, & Stepanovic, 2011). Those who exhibit personality characteristics of hostility and inflexibility have an increased response to chronic stress (Lecic-Tosevski et al., 2011; Wheaton, 1983). How individuals appraise stressful life changes is also based on coping styles and strategies. Coping describes the "cognitive and behavioral efforts to manage" a stressor (Folkman, Lazarus, Gruen, & DeLongis, 1986). Coping serves to deal with the issue creating stress and manage the emotional side-effects created by the stressor (Folkman et al., 1986).

Multiple coping strategies exist and they encompass how one primarily approaches the management of a stressful event. Problem-solving-oriented coping strategies, such as "planful" problem solving, have been shown to decrease the stress response while reactive strategies such as "confrontive" coping are associated with an increased stress response (Folkman et al., 1986; Lazarus & Folkman, 1984).

Other factors in stress appraisal are the external resources and social support that individuals have at their disposal when confronted with a stressful life event. Research has consistently shown that social support dampens the physical and emotional effects of stress on health (Berkman & Kawachi, 2000; P. A. Thoits, 2011). Social support can come in the form of emotional, informational, and instrumental support (P. A. Thoits, 2011). Emotional support is comprised of displays of "caring and encouragement" (P. A. Thoits, 2011). Informational support comprises assistance through advice or knowledge (P. A. Thoits, 2011). Instrumental support provides "material assistance" to an individual (P. A. Thoits, 2011). These practical types of social support may influence stress appraisal when the availability of external resources helps mitigate a stressor and can help explain how social support influences stress appraisal (P. A. Thoits, 2011). Personality characteristics, coping styles and strategies, external resources, and social support can have important influences on stress appraisal and the physical and psychological effects of stress (Lazarus & Folkman, 1984; Lecic-Tosevski et al., 2011; Spruill, 2010; Steptoe, 1991; P. A. Thoits, 2011; Wheaton, 1983).

It is also important to note that stress appraisal is not linear. Iterations of appraisal and stress response occur as individuals consider and reconsider the impact of life changes (Steptoe, 1991; Tomaka, Blascovich, Kelsey, & Leitten, 1993) and their available coping resources (McEwen & Stellar, 1993). Cohen (1995) presents a transactional model of stress where the introduction of a stressor leads to appraisal and a response that influences the stressor, which leads to further appraisal and response (S. Cohen et al., 1995). This cyclical process is key to appreciating the "dynamic nature" of stress and appraisal over time (S. Cohen et al., 1995).

2.7 The Stress Response

Stress as a general term is used to describe both the exposure and the response to the stressor (Foody, James, & Leader, 2015). The stress response is a result of experiencing the stressful exposure, the appraisal process, and the physical and emotional reaction that was provoked (Foody et al., 2015). The stress response is influenced by existing vulnerability and resistance and determines the path through which health outcomes might be affected (Steptoe, 1991). The stress response can affect multiple body systems that can prompt changes in affective, cognitive, autonomic, neuro-endocrine, and immunological function. Examples of such effects include increased heart rate, changes in mood, trouble sleeping, increased blood pressure and glucocorticoid production, and greater susceptibility to the common cold (S. Cohen, Tyrrell, & Smith, 1991; Miller, Cohen, & Ritchey, 2002; Peggy A. Thoits, 1983; Tomaka & Blascovich, 1994). The stress response is persistent even when stress is unacknowledged, such as in individuals with avoidant coping strategies (Steptoe, 1991). The stress response impacts health through three major paths: behavioral, psychological, and physiological (Steptoe, 1991). Through these paths, stressful life changes can have an influence on health outcomes (Hammen, 2005; McEwen & Stellar, 1993; RAND Health's Center for Military Health Policy Research, 1999; Steptoe, 1991).

Behavioral Path

Stress can negatively influence health through behavioral paths when an individual turns to high-cost health behaviors to cope with stress, such as tobacco or substance abuse (Krantz et al., 1985; McEwen & Stellar, 1993). Smoking causes heart disease and is the leading cause of preventable disease and disability in the U.S. (Health, 2018a, 2018b). Stress is a significant risk factor for tobacco use and smoking relapse among former smokers (Lawless, Harrison, Grandits, Eberly, & Allen, 2015). Chronic stress is predictive of alcohol dependency among men with avoidant types of coping strategies (Lynne, Russell, Skinner, Frone, & Mudar, 1992) and stress is positively associated with drug abuse in certain populations (Sinha & Jastreboff, 2013).

Stress can also impact health through behavioral paths when undesirable changes to dietary habits and physical activity occur. Stress has been shown to affect a number of health behaviors and health outcomes, including obesity, (Liu & Umberson, 2015; Wardle, Chida, Gibson, Whitaker, & Steptoe, 2011) especially when individuals employ unhealthy eating behaviors as coping strategies (Holton, Barry, & Chaney, 2016; Laugero, Falcon, & Tucker, 2011). Greater perceived stress is associated with increased sweet and snack consumption and lower physical activity levels leading to weight gain (Block, He, Zaslavsky, Ding, & Ayanian, 2009; Laugero et al., 2011; Proper, Picavet, Bogers, Verschuren, & Bemelmans, 2013). Stress is associated with relapses in overeating behaviors and stress management is an important component of dietary behavioral change strategies (Foreyt & Carlos-Poston, 1998).

Stressful experiences such as relocation may change behavior due to the difficulty of maintaining eating routines and relying on convenience foods during relocations ("The never-ending PCS," n.d.). Disrupted routines related to food procurement and preparation may also effect eating behaviors leading to weight gain (Jastran, Bisogni, Sobal, Blake, & Devine, 2008). The disruption of daily routines may affect women more as they are more likely to be the primary flood planner and preparer (Sobal, Rauschenbach, & Frongillo, 2003). When stress alters behavior either through changes in habits or routines or through the use of substances as coping mechanisms, the development of undesirable health outcomes such as weight gain and cardiovascular risk factors can result.

Psychological Path

Stress can affect psychological health by placing individuals at risk for depression, anxiety, sleep, or adjustment disorders, (S. Cohen & Rodriguez, 1995; Hammen, 2005) especially when no useful coping response is available (McEwen & Stellar, 1993). Hammen (2005) found that in community samples, 80 percent of cases of depression were preceded by major life events, including a linear relationship between the severity and number of stressful life events with the development of depression (Hammen, 2005). Stressful life events have been associated with anxiety; both feelings of anxiety and the medical diagnosis of anxiety disorders (Johnston & Wallace, 1990; Lazarus & Folkman, 1984). Stressors such as physical injury can increase the risk of developing anxiety and mood disorders, due to the loss of control associated with physical limitations (S. Cohen & Rodriguez, 1995).

The relationship between stress and sleep disturbances is less straightforward than other aspects of stress and health because stress affects sleep and lack of sleep exacerbates stress (Partinen, 1994). The strong relationship between stress and depression and the high incidence of insomnia among those with depression further complicates the relationship between stress and sleep disorders. Research shows that insomnia increases the risk of long-term depression and that most patients with a diagnosis of depression report sleep disturbances (Partinen, 1994). Psychosocial stress is a risk factor for developing insomnia and depression, (Sapolsky, 1996; Waters, Adams, Binks, & Varnado, 1993) while studies also show that insomnia is associated with risk of clinical depression (Gillin, 1998). Depression and obesity have also been shown to have a reciprocal relationship with depression being predictive of obesity and obesity increasing the risk of depression (Luppino et al., 2010).

Stress response disorder, which was previously referred to as adjustment disorder, (Kocalevent, Mierke, Danzer, & Klapp, 2014) is characterized as "maladaptive responses to severe or continued stress" (Kocalevent et al., 2014) that typically appears within three months after the occurrence of a stress event (Horowitz, 1986). By definition, stress response disorder is a result of one or more stressful life events that precipitate a "meaningful change in life, resulting in a disturbance in social functioning that is in excess of what would be expected" (Carta, Balestrieri, Murru, & Hardoy, 2009). Research on the relationship between stress response disorder and stressful life events emphasize that even brief events may lead to psychopathologic changes that place individuals at risk for psychiatric disorders (Carta et al., 2009; Horowitz, 1986). Research on the role of life events in the development of mental illness found that 60% percent of those diagnosed with a mental disorder, had experienced a "severely stressful" life event in the two weeks preceding onset of the disorder (Horowitz, 1986).

Although stress is related to psychological health, aspects of psychological health are likely related to each other in ways this research will not elucidate. Sleep disorders may be related to stress but may also be a result of anxiety, depression, or adjustment disorders – or a combination of all three. Therefore it is likely that health outcomes stemming from stressful life changes are a result of an interaction between the environment, biology, and psychology; (Horowitz, 1986) and that the full process by which an individual's health is affected by the experience of stressful changes is unique and complex.

Physiological Path

Stress can influence physiology by increasing risk of hypertension and cardiovascular disease (Krantz et al., 1985; Spruill, 2010) and by accelerating atherosclerosis (McEwen & Stellar, 1993). The body responds to stress by regulating complex body systems including the hypothalamus-pituitary-adrenal (HPA) axis, the sympathetic adrenomedullary system, and the renin-angiotensin-aldosterone system (Lagraauw et al., 2015). Exposures to stress stimulates these systems leading to increased heart rate, blood pressure, and endothelial dysfunction which is a trigger for atherosclerosis (Lagraauw et al., 2015). Stress can further exacerbate atherosclerosis by creating inflammation that dampens the immune response, increasing production of inflammatory markers that accelerate diseases progression (Lagraauw et al., 2015; Tosevski & Milovancevic, 2006).

Allostasis describes the physiological response to stress that regulates hormones, temperature, and blood pressure based on environmental challenges (Logan & Barksdale, 2008; Schulz & Northridge, 2004). Allostatic load refers to the wear and tear on regulatory systems in response to chronic stress that leads to the inability of the body to adapt, which can contribute to the physiological changes that result in chronic disease such as hypertension and dyslipidemia (Logan & Barksdale, 2008; McEwen & Stellar, 1993).

In summary, stressful exposures can cause alterations to an individual's physiology that lead to undesirable health outcomes. When combined with the behavioral or psychological effects of stress, the effects of stress on health can be considerable.

2.8 Vulnerability and Resistance

Underlying the relationship between stress and health outcomes is the concept of vulnerability and resistance, which influences the stress response, disease mechanisms, and health outcomes. Vulnerability and resistance describes the "nature of persons and their contexts" including age, genetics, health status, and physical fitness (S. Cohen & Rodriguez, 1995; Steptoe, 1991). These individual factors that influence vulnerability or predisposition are involved in the development of disease (Carta et al., 2009). Age influences the degree of resistance older individuals have to the effects of psychosocial stress, and once physical abilities decline older persons display greater vulnerability to stressful life changes (Lecic-Tosevski et al., 2011). Genetics has a role in disease development, with some individuals displaying a genetic disposition towards heart disease or diabetes (Atkinson & Eisenbarth, 2001; Bruneau, 2008; El Rouby & Cooper-DeHoff, 2015). Physical fitness is a protective factor in the relationship between stress and illness (Lydeard & Jones, 1989). For those who already have a preexisting condition, stress heightens the risk of individual illness, such as myocardial infarction for those with high atherosclerosis (Rabkin & Struening, 1976).

Characteristics of vulnerability and resistance are highly individual and greatly influence the relationship between stressful life changes and health outcomes (Cassel, 1976). In research on psychiatric disorders where stressful life changes had preceded the diagnosis of a mental condition, 20% of the study population not diagnosed with a psychiatric disorder had also experienced a "severely stressful" event, which highlights the concepts that stressors do not affect everyone the same way (Horowitz, 1986). Stressful life changes and the process of responding to those changes can initiate ill health or the progression and severity of health conditions (Steptoe, 1991).

Through behavioral, psychological, and physiological paths, stress can produce and exacerbate conditions that can have a significant impact on overall health. Primary objectives of this research are identifying the stressful life changes that are influential on the health of Soldiers and the point of highest risk.

2.9 Nutrition-Related Health Outcomes of Interest

Hyperlipidemia and Blood Pressure Changes

Due to the relationship between stress and the physiological changes that increase the risk of cardiovascular disease, this research aimed to investigate associations between stressful life changes and changes in blood pressure and odds of a hyperlipidemia diagnosis. Cardiovascular risk factors present a significant threat to both individual and unit readiness. In studies on CVD risk factors in service members, hypertension and hyperlipidemia prevalence ranged from 12-38% and 17-31%, respectively (Mcgraw, Turner, Stotts, & Dracup, 2008). Another study found the overall rate of coronary calcification to be 17.6% among Soldiers (Taylor et al., 2005). The documented occurrence of cardiovascular events while service members were deployed to a combat zone demonstrates the risk to both the individual Solder and mission accomplishment (Filardo et al., 2005; McGraw et al., 2011). Soldiers must be ready to deploy to austere conditions with little warning and they must be able to physically perform in demanding operational environments. Soldiers with dyslipidemia or hypertension require medical intervention and monitoring and cannot deploy without a waiver (United States Army, 2016b). The ability of units to be ready to meet mission requirements is threatened when Soldiers are in poor cardiovascular health (McGraw et al., 2011).

Separation for Failure to Maintain Body Composition Standards

A basic and critical requirement of Army service is maintenance of body composition standards as outlined in Army Regulation (AR) 600-9, *The Army Body Composition Program* (United States Army, 2013). Tables B-1 and B-2 of AR 600-9 outline the minimum and maximum allowed weight and body fat percent for male and female Soldiers (Appendix A and B). The Army's height and weight table is based on BMI (Friedl, 2012) but does not follow standard BMI cut points as outlined by the CDC: normal weight: 18.5-24.9; overweight: 25.0-29.9; obesity: $\geq$30.0 kg/m^2 ("About Adult BMI," n.d.). The Army uses more lenient BMI cutoffs established in the 1980s and most recently adjusted in 2006 to better accommodate female physiology (Table 2.1) (Friedl, 2012). The use of more lenient BMI cutoffs is largely due to the concern that BMI may misclassify persons with greater muscularity such as athletes and Soldiers ("About Adult BMI," n.d.; Friedl, 2012). The Army's BMI and body fat percent cutoffs also allow for an "aging effect" that provides leeway in weight and body fatness as Soldiers age (Friedl, 2012).

Height and weight is collected on every Soldier (with exceptions for pregnancy) each April and October before or after a Soldier takes the semi-annual Army Physical Fitness Test (APFT). The APFT is a timed and scored physical fitness test that comprises a 2-mile run, push-ups, and sit-ups. During this time, the Army uses Table B-1 in AR 600-9 (Appendix A) to screen Soldiers for compliance with height and weight standards. Only Soldiers who exceed weight requirements for their height are given a circumference-based "tape test" to estimate body fat percent (United States Army, 2013).

The tape test for Army body fat estimation is based on the Hodgdon and Beckett equation that was developed and validated in 1984 by the Navy at presidential request (Friedl, 2012). The Hodgdon and Beckett equation was adopted military-wide after it was found to be highly correlated with body fat percent estimated by underwater weighing (men: *R* = 0.90, SEE = 3.52; women: *R* = 0.85, SEE = 3.72) (Marriott & Grumstrup-Scott, 1992). Using neck and waist circumferences for men, and neck, waist, and hip circumferences for women, the Hodgdon and Beckett equation predicts percent body fat through the following calculations:

Men: Density = -0.350 x Log_{10} (abdomen II – neck) + 0.155 x Log_{10} (height) +1.032; percent fat = 100 x [(4.95/density) – 4.5]

Women: Density = -0.350 x Log_{10} (abdomen I + hip + neck) + 0.221 x Log_{10} (height) +1.296; percent fat = 100 x [(4.95/density) – 4.5]

When Soldiers are found to exceed the maximum allowable body fat percentage (Appendix B) for their age by the tape test, they are considered out of compliance with body composition standards (United States Army, 2013). These Soldiers are mandatorily enrolled in the Army Body Composition Program (ABCP) (United States Army, 2013). Soldiers who are enrolled in ABCP are reweighed and/or given a tape test every 30 days for six months following body composition failure (United States Army, 2013). According to ABCP, to make satisfactory progress toward reaching body-composition goals, Soldiers must lose 3-8 pounds (1.36-3.63 kg) per month or ≥1% body-fat until they reach body fat targets (United States Army, 2013). Soldiers who do not make satisfactory progress towards meeting body composition standards and do not have an underlying medical condition can be involuntarily separated from the Army through a Chapter 18 discharge (Regulation, 2011). Additionally, Soldiers who fail to meet body composition standards in the following 12 months after removal from ABCP can be involuntarily separated from the Army through a Chapter 18 discharge (Regulation, 2011). For Soldiers who receive a Chapter 18 discharge, the sole reason for separation is failure to adhere to body composition standards (Regulation, 2011). These Soldiers represent the loss of a significant investment of Army resources and understanding what factors contribute to this outcome is of value to Army leadership.

Substantial Weight Gain

The Army's weight and body composition regulations designed to keep Soldiers from becoming overfat must be inclusive to the variation in body shapes found in a population (Friedl, 2004). To address this challenge, the Army's weight screening tables allow for up to a 23 kilogram range between a Soldier's minimum and maximum allowed weight depending on height and gender (Marriott & Grumstrup-Scott, 1992; United States Army, 2013). Even though stressful life changes may precede weight gain, not all Soldiers gain weight to the degree that they exceed body composition standards. For example, a 24-year-old, 72” tall male Soldier may weigh between 140 and 195 pounds per Table B-1 of AR 600-9 (Appendix A). If this Soldier typically weighs 165 pounds but after experiencing stressful life changes he gains 10% of his body weight and weighs 181 pounds the next time he is weighed at a mandatory check, the Soldier has experienced a substantial weight gain – but one that does not put him over his maximum allowable screening weight. Based on Army weight standards, this weight gain would not be concerning, but from a population health perspective, this weight gain puts the Soldier closer to exceeding weight standards in the future and could indicate an increased risk of further weight gain. Likewise, for a 24-year-old, 66” tall female Soldier, the Army allows a weight of between 117 and 156 pounds, which means that this Soldier could experience significant weight changes before exceeding her screening weight. Due to the range of allowable weights in Table B-1, examining those who have a ≥10% weight gain, even if they do not exceed body composition standards, may provide insights into the relationship between stressful life changes and weight gain.

The nutrition-related health outcomes that were used in this study represent those that have operational and practical relevance to the Army. They represent threats to individual Soldier and unit readiness that compromise the ability of the Army to meet mission requirements. Investigating the association between stressful life changes and these outcomes provides novel information that could be used to improve Soldier health and readiness.

2.10 Theoretical framework

The Life-course Perspective

Underlying this research and the conceptualization of the dynamic process of how stressful life changes impact health is the life-course perspective which is a theoretical framework for examining how life changes influence future health (Elder Jr, Johnson, & Crosnoe, 2003). The life-course perspective can be employed to help elucidate the relationship between social context, time, life experience, and health (Wethington, 2005). Life-course constructs of transitions, adaptive strategies, and timing can be used to examine the influence of stressful life changes on nutrition-related health outcomes among Soldiers.

Transitions describe changes in roles and responsibilities that may influence health-behavior trajectories (Gade, 1991; Wethington, 2005). Like stressful life changes, transitions can be both expected and unexpected and are often related to changes in roles and responsibilities (e.g. marriage, promotion, parenting) (Wethington, 2005) that can influence health behaviors and psychological and physiological adjustment. In this research, stressful life changes are conceptualized as transitions that can influence the paths that impact health outcomes. Military service is characterized by changing roles and responsibilities as Soldiers make decisions about military occupations, get promoted, move into command positions, deploy, or attain degrees (Gade, 1991). The transitions associated with military-specific stressful life changes may have the ability to undermine positive health-behaviors or affect the psychology and physiology of Soldiers.

Adaptive strategies are decisions that individuals make in order to adapt to change (Wethington, 2005) and describe how individuals change their behavior in response to transitions or stressful life changes. Stressful life changes experienced over the life-course influence the adaptive strategies that individuals employ. Through behavioral paths, adaptive strategies that involve poor eating behaviors or increased alcohol consumption can lead to poor health outcomes whereas positive changes to health behaviors may improve overall heath (Laugero et al., 2011; Liu & Umberson, 2015). As a result of military service, individuals must employ adaptive strategies to manage Army weight and physical fitness requirements. In the proposed research, adaptive strategies help to explain the behavioral link between the stressful life changes and the nutrition-related health outcomes of interest and are useful for framing the way that stressful changes can impact health over the life-course in a military population.

Timing is a particularly relevant life-course construct in the context of military research. The timing of transitions can be highly influential on future health, based on the developmental stage at which they occur (Gade, 1991). Entry into the military can represent a significant transition with health ramifications (Elder Jr, n.d.). Military transitions such as initial entry into service often occur in conjunction with other stressful life changes such as leaving home, entry into the workforce, or marriage (Gade, 1991). The timing of entry into service, such as during periods of war or peace, can also affect future health by dictating the types of stressful life changes that a Soldier may encounter as part of their military service. This research aimed to examine how the occurrence and timing of stressful life changes influences nutrition-related health outcomes in an Army population.

The life-course perspective is used as a framework for conceptualizing the factors that may influence the stress response and the paths that influence health outcomes.

Time is an influential variable in the effect of stress on health, and is a key component of the life-course perspective and this research. Examining the constructs of transitions, timing, and adaptive strategies in the context of a military population provides relevant insights into the relationship between military service and health.

2.11 Conceptual Model

The proposed research is guided by a conceptual model (Figure 2.1) which is based on the Research and Development Corporation (RAND) report on stress and military health (1999) and Steptoe's (1991) work on stress and illness including the paths through which stress can influence health (RAND Health's Center for Military Health Policy Research, 1999; Steptoe, 1991). Based on key research from the body of literature on stress and health, this conceptual model incorporates the context of the Army and represents the process by which stressful life changes are postulated to lead to changes in nutrition-related health outcomes among Soldiers. As indicated in the conceptual model, the data that were used did not contain every data element believed to play a role in the development of the health outcomes of interest. This constraint is acknowledged but was not a limitation to answering the research questions and specific aims presented previously.

2.12 Summary

The effects of stress on health are well documented in civilian populations. Soldiers are not fundamentally different from civilian populations in many regards, but the unique environment of the military affects the exposures Soldiers have and the context in which they experience them. This research represents one of the few studies on stress among Soldiers and is the first to establish BMI trajectories in this population and examine the associations between stressful life changes and nutrition-related health outcomes.

There is a large body of literature demonstrating the effects of stressful changes, such as marriage on weight gain (Dinour, Leung, Tripicchio, Khan, & Yeh, 2012) and job strain on hypertension and hyperlipidemia (Kivimäki et al., 2002; Lagraauw et al., 2015; Matthews & Gump, 2002). Existing studies are often of a prospective design with data collection intervals ranging from several months in length to several years (Dinour et al., 2012). A feature of this research is that it utilizes the way in which the Army collects health surveillance data allowing for changes in outcomes or exposures to be observed in monthly intervals. The longitudinal aspect and the short intervals between observations contribute novel information regarding life-course occurrences and disease development that are applicable to the military and civilian populations.

The main objectives of this research was to address gaps in knowledge about the shape and determinants of BMI trajectories and the associations between stressful life changes and specific nutrition-related health outcomes in Soldiers.

Specific Aim 1: To model the BMI trajectories of active-duty U.S. Army Soldiers.

RQ1: What is the overall BMI trajectory of the Army and does it differ from the overall BMI trajectory of the general population?

RQ2: What are the most common BMI trajectory groups among Soldiers?

RQ3: Are select sociodemographic and military-specific characteristics associated with BMI trajectory groups of Soldiers?

RQ4: Are there Soldiers with large fluctuations in BMI that would not be identified in group trajectory models?

RQ5: Are there differences between men and women in the shape or determinants of BMI trajectories?

Specific Aim 2: To identify and model the stressful life changes that have the greatest association with substantial weight gain, separation for failure to meet body composition standards, and specific cardiovascular risk factors over time.

RQ6: Is experiencing stressful life changes associated with a change in blood pressure, an earlier onset of hyperlipidemia diagnosis, substantial weight gain, or being separated from the Army for failure to meet body composition standards?

RQ7: Which stressful life changes are most associated with these outcomes?

RQ8: Are there differences in effects between men and women?

Table 2.1: Maximum BMI and body fat percent by sex and age (Friedl, 2012; United States Army, 2013).

Male BMI and Body Fat %, by age					Female BMI and Body Fat %, by age			
Age	17-20	21-27	28-39	40+	17-20	21-27	28-39	40+
BMI	25.8	26.4	27.1	27.5	25.0	25.2	25.5	26.0
BF%	20%	22%	24%	26%	30%	32%	34%	36%

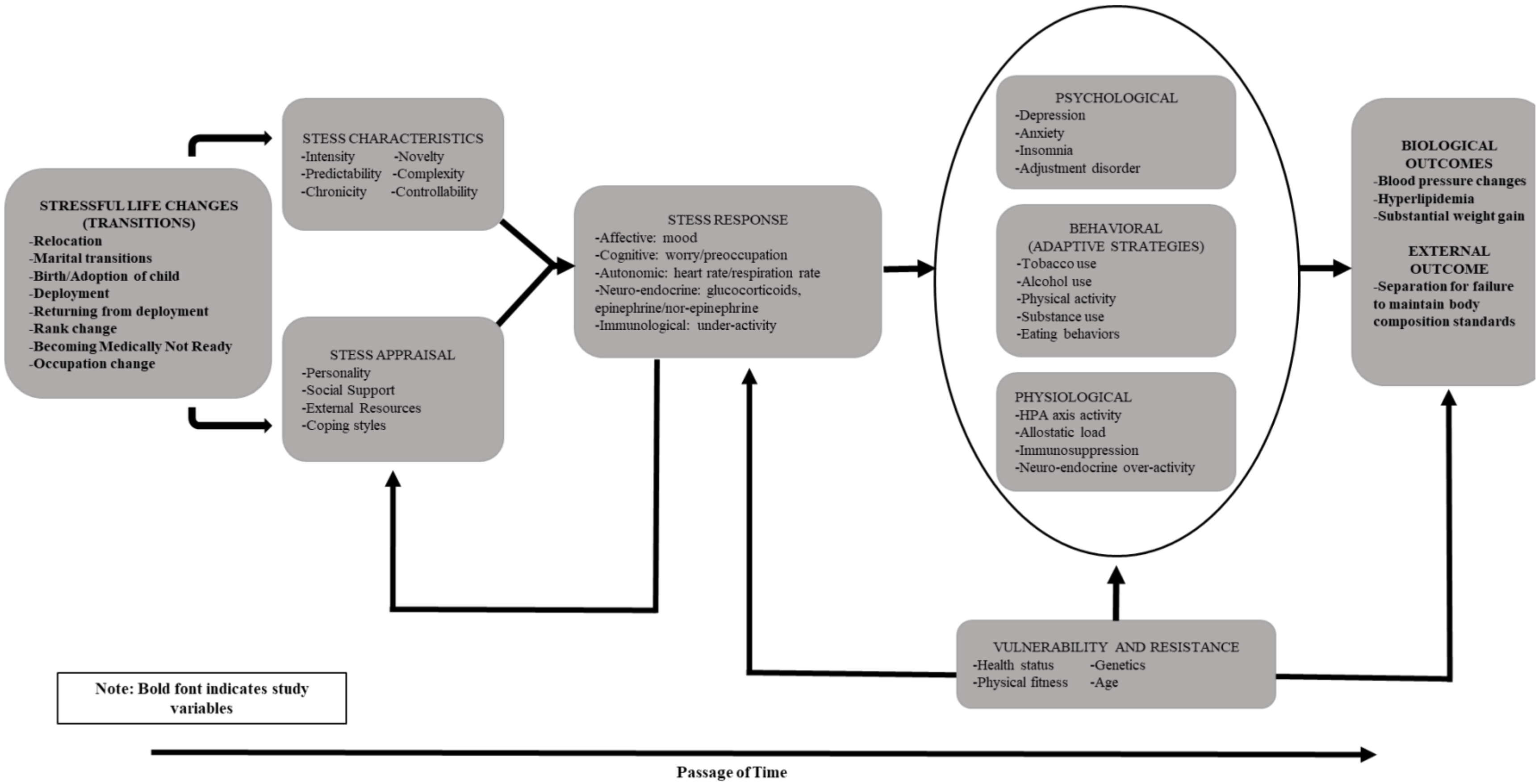

Figure 2.1 Conceptual model of the effects of stressful life changes on nutrition-related health outcomes in the context of the U.S. Army (bold font indicates study variables).

CHAPTER 3

METHODOLOGY

3.1 Setting

The Army is one of three military branches under the Department of Defense (DoD) that encompasses both active-duty, full-time Soldiers and reserve, part-time Soldiers that augment the active-duty force when required ("Organization: Who we are," n.d.). The Army employs two types of personnel: Officers and Enlisted Soldiers. Enlisted Soldiers comprise 82% of the Army and are trained to perform specific tasks and duties required by their unit. Officers encompass the remaining 18% of the total force and are responsible for leading units, planning missions, and managing enlisted personnel ("Structure and Organization," n.d.). All Soldiers are assigned a military occupation with unique job and training requirements. While the day-to-day mission varies for individual Soldiers based on the type of job they hold, the mission of the Army "to fight and win our Nation's wars" means that all Soldiers, regardless of rank or job position, are first and foremost warfighters (*Soldier's Manual of Common Tasks: Warrior Skills Level 1,* 2015). While individual Soldiers have diverse experiences based on the function they serve in the Army, the mission and service requirements also dictate that Soldiers will experience many of the same stressful life changes that are a unique consequence of Army service.

3.2 Data source

Data were from the Stanford Military Data Repository (SMDR), a de-identified longitudinal dataset encompassing health, administrative, and sociodemographic data from all active-duty Soldiers between January 2011 and December 2014. The SMDR was created by merging data from multiple military data systems. Medical diagnosis information came from the Military Health System Data Repository (MDR). Sociodemographic data such as marital status came from the Defense Manpower Data Center (DMDC). Weight, height and BMI measures were from the Comprehensive Ambulatory/Professional Encounter Record (CAPER), Periodic Health Assessments (PHA), and Digital Training Management System (DTMS), the latter of which captured data from the semi-annual Army Physical Fitness Test. Physical limitation data came from eProfile, the tracking system for Soldiers with a medical limitation to duty. These data were organized as a person-month-based panel providing up to 48 months of observation. The sample was restricted to Soldiers 17-62 years old (n=827,126), which is the typical age range of Soldiers due to minimum entrance and mandatory retirement rules.

3.3 IRB Approvals

This research was approved by the University of South Carolina and the Stanford University institutional review boards and the Defense Health Agency's Human Research Protection Office.

3.4 Methodology for Manuscript 1

The aims of this manuscript were to (1) establish the overall BMI trajectory of the Army by examining BMI changes associated with aging, (2) find the most common trajectory groups among Soldiers, (3) investigate the relationship between BMI trajectories and select sociodemographic and military-specific characteristics, and (4) determine if there were Soldiers with large fluctuations in BMI.

Measures

The dependent variable was BMI measured by trained medical staff such as nurses or heath technicians at military medical facilities or by trained non-commissioned officers during mandatory body composition checks. BMI observations were screened for biologically implausible values within the population and within each person's data by subtracting each Soldier's mean BMI from all of their available BMI observations. BMI measures varying ±5 BMI points from the person's mean were considered implausible values. This permitted any two BMI observations to be up to 10 BMI points apart (approximately 23 kg) before a value was considered biologically implausible within a person's data. To account for the biological influence of pregnancy, BMI observations taken in a month when a woman's medical record had a diagnosis code for pregnancy were removed. These cleaning procedures removed 464,729 or 2.2% of the total number of possible BMI observations.

Independent variables

Sociodemographic variables were age, education, marital status, race/ethnicity, service years, branch of service, and rank. For time-variant variables, the first observed value in the analysis was used. Race and ethnicity were separate variables and were combined using federal guidelines (Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian/Pacific Islander, Multi-Racial, American Indian/Alaskan Native, Hispanic) ("OMB Directive 15: Race and Ethnic Standards for Federal Statistics and Administrative Reporting," n.d.).

Duty limitations were determined if a Soldier was MNR for deployment by a code of 3 or 4 indicating a substantial duty limitation in one or more categories used to quantify medical readiness in the eProfile system: physical capacity, upper extremities, lower extremities, or psychiatric (United States Army, 2016b). Exceeding weight standards was determined by a Soldier exceeding weight and relative body fat standards (United States Army, 2013) during the study interval.

Statistical Analysis

Data were analyzed using Stata, version 14.2 (StataCorp, College Station, TX). All analyses were stratified by gender given expected differences in BMI (Flegal et al., 2016). The overall BMI trajectory of the Army was determined through examining BMI changes associated with aging by graphing the mean BMI of Soldiers at each year of age.

The most common BMI trajectory groups among Soldiers were modeled through group-based trajectory modeling (GBTM) using the Stata *traj* procedure (B. L. Jones & Nagin, 2012). GBTM is used to find distinct trajectory groups within a population using multinomial modeling (B. L. Jones & Nagin, 2012; Tu et al., 2015). GBTM is a form of finite mixture models used to identify groups of individuals following similar developmental trajectories in an outcome over time, and uses probability distributions based on maximum likelihood estimation to determine group membership (B. L. Jones & Nagin, 2007, 2012; Nagin & Odgers, 2010).

Models with 3, 4, and 5 trajectory groups were examined with months as a quadratic, cubic, or quartic polynomial and specified as a censored normal distribution.

BMI skewness and kurtosis were 0.43 and 3.35, respectively. Similarly to other BMI trajectories research, (Walsemann et al., 2012) BMI was used without transformation after preliminary models using the natural log of BMI did not appreciably change model outcomes. The time scale was calendar month to capitalize on the frequent BMI observations.

Preliminary models produced estimates reflecting differences in magnitude between the mean BMI of the trajectory groups instead of BMI changes over time. Graphs of these models displayed horizontal lines showing only differences in mean BMI between the groups, not how BMI changed over time. This was corrected by centering mean BMI for each individual at zero, adding back the overall mean of individuals when creating final graphs.

Models were evaluated by increasing the number of trajectories and order of the polynomial. Cubic models required ≥3 BMI observations for each individual, ≥4 for a quadratic term, and ≥5 for a quartic term to include Soldiers with enough BMI observations to contribute to models. The criteria for model selection were the percent of Soldiers in each trajectory, complexity of the trajectories, the stability of the estimates, and the size of the Bayesian Information Criterion (BIC) statistic. The final model of 4 trajectories and months as a quartic polynomial was deemed to distinctly describe the main trajectories of Soldiers and had the smallest BIC.

A total of 14.8% of the population was excluded from the models due to insufficient BMI data (Figure 4.1). Soldiers excluded from the *traj* procedure were primarily junior enlisted with <4 service years (74.1% men, 78.8% women). Of the 122,794 Soldiers excluded from the *traj* procedure, 94,318 (76.8%) exited the Army in

2011 or entered the Army in 2014, leaving too little time to accumulate the ≥5 BMI observations required for final models.

GBTM does not model the intra-individual variability representing the non-trend portions of the trajectories (Frongillo & Rowe, 1999). To identify Soldiers with large intra-individual variability, such as BMI fluctuations caused by weight cycling, person-specific growth curves were fit to a random sample of 7,208 men and 7,069 women with ≥8 BMI observations. To determine the degree of BMI fluctuations over time, the root mean squares error (RMSE) was obtained from linear regression models of BMI with time specified as a quartic polynomial. Soldiers with a RMSE of ≥1.0 correspond to those with fluctuations of two or more BMI points, or about 4.5 kg, over the study period. Similarly to other research,(Field et al., 1999) weight cycling was considered to be ≥3 bidirectional changes of ≥2 BMI points as seen by visual inspection of graphs of BMI over time in Soldiers with an RMSE of ≥1.0.

Bivariate associations described the characteristics of individuals in the trajectory groups. Multinomial logistic regression using BMI trajectory as the dependent variable identified characteristics associated with trajectory membership. Race/ethnicity and marital status were simplified for regression models. Age categories used in the Army's weight allowance tables were used in regression models: 17-20 years, 21-27, 28-39, and ≥40. Due to Army age requirements, cross-classification of sociodemographics showed categories with few or no Soldiers (e.g. Soldiers ages 17-20 with >10 service years). These categories were collapsed to create a combined variable for age and service years. In final models, rank and branch of service were removed since service years drives rank attainment and women were not in all branches.

3.5 Methodology for Manuscript 2

The aims of this prospective cohort study were to determine if experiencing stressful life changes is associated with (1) a change in blood pressure or (2) an earlier onset of hyperlipidemia diagnosis, substantial weight gain, or being separated from the Army for failure to meet body composition standards. This research also aimed to determine which stressful life changes were most associated with these outcomes and if there were differences in associations between men and women, hypothesizing that for the outcomes of hyperlipidemia and substantial weight gain, the most stressful life changes would be marital transitions, relocation, and becoming medically not ready (MNR) for deployment and that there would be gender differences in the magnitude of the associations.

Nutrition-related health outcomes

Study outcomes were changes in systolic blood pressure (mm Hg), diagnosis of hyperlipidemia, substantial weight gain, and separation from the Army for failing to meet body composition standards. Blood pressure is an average of any systolic blood pressure measured in a given month by trained medical staff such as nurses or heath technicians at military medical facilities. Diagnosis of hyperlipidemia was determined by the presence of an International Classification of Diseases (ICD)-9 code for hyperlipidemia/dyslipidemia in a Soldier's outpatient medical record. Weight was measured by trained medical staff such as nurses or heath technicians at military medical facilities or by trained non-commissioned officers during mandatory body composition checks. Weight observations were screened for biologically implausible values within the population and within each person's data by subtracting each Soldier's mean weight from all of their available weight observations. Weight measures varying ±11.5 kg (which equates to about 5 BMI points) from the person's mean were considered implausible values. This rule permitted any two weight observations to be approximately 23 kg apart before a value was considered biologically implausible within a person's data. In women, weight observations taken in a month when an ICD-9 code for pregnancy was found in the medical record were removed. These cleaning procedures removed 54,842 weight observations or 0.25% of the total. Substantial weight gain occurred if a Soldier's weight exceeded their first observed weight by ≥10% over the study period. Separation from the Army for failing to meet body composition standards applies to Soldiers whose inability to meet body composition requirements is the sole basis of their separation and was determined by a chapter 18 separation code in the Soldiers' personnel records (United States Army, 2016a).

Exposure variables

Exposure variables were stressful life changes: changes in marital status, becoming deployed to a combat zone (or returning from deployment), relocation, adding a child, change in rank, change in military occupation, or development of a physical limitation to duty. Changes in marital status, number of children, relocation, rank, and occupation were determined from personnel records. Change in marital status occurred if a Soldier became single through any means (e.g. divorced) or became married. A Soldier could have added a child either by adoption or birth. Relocation was determined by a change in duty station based on zip code. Change in rank could be achieved by promotion or demotion. Change in occupation was determined by a change in military job code. Deployment was based on personnel records indicating the Soldier had been deployed to a combat zone. Physical duty limitations were determined if a Soldier was medically not ready (MNR) for deployment by a code of 3 or 4 indicating a substantial duty limitation in one or more categories used to quantify medical readiness in the eProfile system: physical capacity, upper extremities, lower extremities, or psychiatric (United States Army, 2016b). MNR is akin to a serious injury or illness in civilians.

Risk Period

The risk period was the period of time in which it is conceivable for the occurrence of a stressful life change to have affected behavioral and physiological paths leading to the development of a study outcome. The risk period for each outcome was based on the available literature taking into account Army regulations and structural factors, such as those related to separating a Soldier from service. The risk period for blood pressure was considered to be concurrent with the occurrence of the stressful life change since blood pressure is labile in response to stress (Black & Garbutt, 2002; Mustacchi, 1990). The risk period for hyperlipidemia was three to six months prior to diagnosis of hyperlipidemia due to the length of time necessary for hyperlipidemia to develop (Stoney, Niaura, et al., 1999; Tang et al., 1998). The risk period for substantial weight gain was seven to twelve months before the $\geq$10% weight gain threshold had been reached and was based on the amount of time weight gain can occur, (Helander, Wansink, & Chieh, 2016) considering that in the Army weight gain is discouraged (United States Army, 2013). Risk period for separation from the Army was 10-18 months before separation based on Army procedures for separating Soldiers from service (United States Army, 2013; United States Army, 2016a).

Sociodemographic and control variables

Rank, marital status, branch of Army, and number of children were used in descriptive tables. Branch of Army (combat, combat support, combat service support) was used descriptively but not as a control variable since women were not in all branches. Time-varying control variables were years of service, age, and education level. The only time invariant control variable was race/ethnicity. Race and ethnicity were separate variables and were combined using federal guidelines (Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian/Pacific Islander, Multi-Racial, American Indian/Alaskan Native, Hispanic) ("OMB Directive 15: Race and Ethnic Standards for Federal Statistics and Administrative Reporting," n.d.).

Statistical Analysis

Data were analyzed using Stata, version 14.2 (StataCorp, College Station, TX). All analyses were stratified by gender given expected differences in the associations of stress between men and women (Liu & Umberson, 2015; Udo, Grilo, & McKee, 2014). The significance level was set as p-value < 0.01. Event history analysis was used to model the association of stressful life changes with study outcomes (Yamaguchi, 1991). Nutrition-related health outcomes were non-repeatable or repeatable, modeled as a one-way or two-way transition, respectively. Non-repeatable outcomes of hyperlipidemia, substantial weight gain, and separation from the Army for failure to meet body composition standards were analyzed using discrete-time logit models of a non-repeatable one-way transition. The outcome data were constructed such that once a non-repeatable event occurred, an individual's subsequent data were not included. Blood pressure was considered a repeatable outcome and was analyzed using a discrete-time regression model of a repeatable two-way transition. Models were estimated using the robust cluster variance estimator.

Two of the stressful life changes, change in marital status and deployment, involved a change in status, e.g., being married or single or being deployed or not deployed. For these status variables, a variable that reflected their status at any given month and lagged variables that reflected their status in the month(s) prior to identify those who had a change in status were used. Additionally, interactions between lagged and current status variables were examined to differentiate the effect of transitions from one status to another (e.g. the change from married to single versus the transition from single to married). Lagged variables for the outcome of blood pressure to account for blood pressure at an observation the month before were also created. This meant that Soldiers were required to have at least two blood pressure measures taken in consecutive months to be included in the analysis. The mean number of blood pressure measures in those with consecutive measures was 8.97 (SD=4.37, range 2-41, skew: 0.83, kurt: 3.93) in men and 12.35 (SD=5.5, range 2-40; skew: 0.46, kurt: 3.00) in women. Due to the requirement of consecutive measures and the possible influence of Soldiers with more blood pressure measures on estimates, differences in mean blood pressure between those included and those excluded in final models were examined. The mean blood pressure of men included and excluded was 125.1 (SD=11.5) and 123.0 (SD=11.9), respectively. The mean blood pressure of women included and excluded was 117.1 (SD=11.4) and 123.7 (SD=11.8), respectively.

Using the hypothesized risk period, models of hyperlipidemia and substantial weight gain were tested in two month increments prior to the event (e.g. 1-2 months prior, 2-3, months prior), with individual stressful life changes, lagged variables, interactions, and controls, using the data to confirm the two-month interval of highest odds. Out of this two-month interval, each of these months were then tested separately with the month closest to the event being chosen if the regression coefficients were not appreciably different, to best represent the month when the event developed. Models of separation for body composition failure were narrowed to an 11-month period where estimates showed the largest coefficient. Adding a child was not included in models of substantial weight gain in women due to the influence of pregnancy on weight gain, which is a desirable occurrence during pregnancy. Occupation change was not included as an exposure variable in models of women due to the small number of women who changed military occupations.

Model fit was assessed by comparing statistical significance and the root mean squared error (RMSE) or the area under the receiver operating characteristic (ROC) curve to assess model prediction and discrimination for logit models. Final models presented are of the outcome at the month(s) where the effect of the stressful life changes were greatest, controls, and the fewest number of lagged variables and interactions found to contribute to model fit. For odds ratios less than one, the inverse association was calculated and reported in the discussion to aid interpretation (e.g., an odds ratio of 0.80 equates to 1.25 lower odds). A z test was used to test differences between men and women since models were stratified by gender. The z test result is equivalent to including gender as an interaction term in models not stratified.

Since the main models estimate the association of an exposure on an outcome at a specific month, the survival functions for substantial weight gain for those who became married compared to those who did not over a 12-month period were also examined. The coefficients from a sequence of models over 12 months were used to calculate the hazard and survival function at each month, and then the cumulative probability of weight gain in men and women at each month after marriage occurred.(Yamaguchi, 1991) The difference in cumulative probability of weight gain over 12 months was found by subtracting the probability of weight gain in those who married from the probability of weight gain in those who did not marry.

3.6 Summary

This chapter outlined the methodology used to answer the research questions that were developed from the specific aims guiding this research. Chapter 4 presents the results of the analysis conveyed in the form of two distinct manuscripts.

CHAPTER 4

RESULTS

4.1 Manuscript 1

BODY MASS INDEX TRAJECTORIES OF ACTIVE-DUTY U.S. ARMY SOLDIERS, 2011-2014[1]

[1]Jayne, J.M., Blake, C.E., Frongillo, E.A., Liese, A.D., Cai, B., Nelson, D. A., Kurina, L.M., Funderburk, L. To be submitted to *Preventive Medicine*.

Abstract

To establish the shape and determinants of body mass index (BMI) trajectories among Soldiers, we aimed to (1) model the overall BMI trajectory of Soldiers, (2) find the most common trajectory groups among Soldiers, (3) investigate the relationship between BMI trajectories and sociodemographic and military-specific characteristics, and (4) determine if there were Soldiers with large fluctuations in BMI. Study population included all U.S. Army Soldiers on active-duty between 2011 and 2014 who were age 17-62 (n=827,126). With longitudinal data from the Stanford Military Data Repository, we used group-based trajectory modeling to identify the BMI trajectories of Soldiers and multinomial logistic regression to estimate associations between Soldier characteristics and trajectory membership. Four distinct BMI trajectory groups were found: increasing, decreasing, constant, and inconstant. The constant, increasing, and decreasing trajectories were similar in shape and percentage between men and women. The constant trajectory had the fewest Soldiers who exceeded weight standards or had duty limitations. The increasing trajectory was associated with marriage and fewer service years. The decreasing trajectory was associated with more service years and higher educational attainment. The inconstant trajectory differed in shape between men and women. Over 6% of men and 12% of women had fluctuations in BMI indicative of weight cycling. Characteristics of Soldiers, such as service years, age, and limitations to duty were associated with BMI trends. Understanding and utilizing these characteristics may assist the Army in targeting resources aimed to improve Soldier health and combat readiness.

Key words: Body mass index trajectories; longitudinal; self-monitoring; military; weight cycling; group-based trajectory modeling

Introduction

U.S. Army Soldiers have similar sociodemographic characteristics to civilians, but military-specific characteristics and demands, including higher levels of physical activity, likely affect trends in body mass index (BMI). In addition to physical fitness tests, twice yearly the Army assesses a Soldier's compliance with weight and body composition standards using BMI-based weight-screening tables and circumference-based relative body fat assessments (Friedl, 2012; United States Army, 2013). These requirements result in the Army representing a population required to self-monitor weight to meet these standards. Despite these requirements, BMI has risen among members of the military, though to a lesser degree than in civilian populations (T. J. Smith et al., 2012).

BMI as an anthropometric tool has been essential for population surveillance and documenting the obesity epidemic and its health consequences (Prentice & Jebb, 2001). In civilians, characteristics such as gender (Flegal et al., 2016) affect BMI and older age, minority status, and low education are predictors of obesity (Lahmann, Lissner, Gullberg, & Berglund, 2000; Zhang & Wang, 2004). Military-specific characteristics such as duty limitations, rank, or branch of Army may be associated with BMI, but relative little research is available on the sociodemographic or military-specific characteristics associated with BMI (T. J. Smith et al., 2012) or longitudinal BMI trends among Soldiers (Reyes-Guzman et al., 2015). Examining how Soldier characteristics relate to BMI trends may inform future research aimed at increasing compliance with weight standards and corresponds with Army priorities of improving combat readiness (*Army Medicine Campaign Plan*, 2017).

One use for BMI in population surveillance is to model the BMI trajectories of a population over time (Heo et al., 2003). Many studies are available on BMI trajectories of adults, children, and some specialized populations, (Timothy J. Cole et al., 1995; de Groot et al., 2014; Jackson et al., 2012a; Tu et al., 2015; Walsemann et al., 2012) but few longitudinal studies of BMI trajectories in military populations exist. Using longitudinal data representing the entire population of the Army over a four-year period, we aimed to (1) establish the overall BMI trajectory of the Army by examining BMI changes associated with aging, hypothesizing there would be substantive differences between the BMI trajectory of Soldiers and BMI trajectories of civilians observed elsewhere, (Jackson et al., 2012a; National Center for Health Statistics (U.S.) & National Health and Nutrition Examination Survey (U.S.), 2016) (2) find the most common trajectory groups among Soldiers, hypothesizing there would be at least three distinct BMI trajectories, a majority group with a constant BMI, those who gained BMI, and those with an inconstant BMI, (3) investigate the relationship between BMI trajectories and select sociodemographic and military-specific characteristics, hypothesizing certain Soldier characteristics would be associated with BMI trajectory, and (4) determine if there were Soldiers with large fluctuations in BMI, hypothesizing fluctuations would be common.

Methods

Data and study population

Data were from the Stanford Military Data Repository (SMDR), a de-identified longitudinal dataset encompassing health, administrative, and sociodemographic data from all active-duty Soldiers between January 2011 and December 2014. The SMDR was created by merging multiple military data systems (Table 4.1). These data were organized as a person-month panel providing up to 48 months of observation. The sample was restricted to Soldiers 17-62 years old (n=827,126), which is the typical age range of Soldiers due to minimum entrance and mandatory retirement rules. The study was approved by the University of South Carolina and the Stanford University institutional review boards and the Defense Health Agency's Human Research Protection Office.

Measures

The dependent variable was BMI measured by trained medical staff such as nurses or heath technicians at military medical facilities or by trained non-commissioned officers during mandatory body composition checks. BMI observations were screened for biologically implausible values within the population and within each person’s data by subtracting each Soldier’s mean BMI from all of their available BMI observations. BMI measures varying ±5 BMI points from the person’s mean were considered implausible values. This permitted any two BMI observations to be up to 10 BMI points apart (approximately 23 kg) before a value was considered biologically implausible within a person's data. To account for the biological influence of pregnancy, we removed BMI observations taken in a month when a woman’s medical record had a diagnosis code for pregnancy. These cleaning procedures removed 464,729 or 2.2% of the total number of possible BMI observations (Figure 4.1).

Independent variables

Sociodemographic variables were age, education, marital status, race/ethnicity, service years, branch of service, and rank. For time-variant variables, we used the first observed value in the analysis. Race and ethnicity were separate variables and were combined using federal guidelines (Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian/Pacific Islander, Multi-Racial, American Indian/Alaskan Native, Hispanic) ("OMB Directive 15: Race and Ethnic Standards for Federal Statistics and Administrative Reporting," n.d.).

Duty limitations were determined if a Soldier was Medically Not Ready (MNR) for deployment by a code of 3 or 4 indicating a substantial duty limitation in one or more categories used to quantify medical readiness in the eProfile system: physical capacity, upper extremities, lower extremities, or psychiatric (United States Army, 2016b). Exceeding weight standards was determined by a Soldier exceeding weight and relative body fat standards (United States Army, 2013) during the study interval.

Statistical Analysis

Data were analyzed using Stata, version 14.2 (StataCorp, College Station, TX). All analyses were stratified by gender given expected differences in BMI (Flegal et al., 2016). We determined the overall BMI trajectory of the Army through examining BMI changes associated with aging by graphing the mean BMI of Soldiers at each year of age.

The most common BMI trajectory groups among Soldiers were modeled through group-based trajectory modeling (GBTM) using the Stata *traj* procedure (B. L. Jones & Nagin, 2012). GBTM is used to find distinct trajectory groups within a population using multinomial modeling (B. L. Jones & Nagin, 2012; Tu et al., 2015). GBTM is a form of finite mixture models used to identify groups of individuals following similar developmental trajectories in an outcome over time, and uses probability distributions based on maximum likelihood estimation to determine group membership (B. L. Jones & Nagin, 2007, 2012; Nagin & Odgers, 2010).

Models with 3, 4, and 5 trajectory groups were examined with months as a quadratic, cubic, or quartic polynomial and specified as a censored normal distribution. BMI skewness and kurtosis were 0.43 and 3.35, respectively. Similarly to other BMI trajectories research (Walsemann et al., 2012), we used BMI without transformation after preliminary models that used the natural log of BMI did not appreciably change model outcomes. The time scale was calendar month to capitalize on the frequent BMI observations.

Preliminary models produced estimates reflecting differences in magnitude between the mean BMI of the trajectory groups instead of BMI changes over time. Graphs of these models displayed horizontal lines showing only differences in mean BMI between the groups, not how BMI changed over time. We corrected this by centering mean BMI for each individual at zero, adding back the overall mean of individuals when creating final graphs.

Models were evaluated by increasing the number of trajectories and order of the polynomial. Cubic models required ≥3 BMI observations for each individual, ≥4 for a quadratic term, and ≥5 for a quartic term to include Soldiers with enough BMI observations to contribute to models. The criteria for model selection were the percent of Soldiers in each trajectory, complexity of the trajectories, the stability of the estimates, and the size of the Bayesian Information Criterion (BIC) statistic. The final model of 4 trajectories and months as a quartic polynomial was deemed to distinctly describe the main trajectories of Soldiers and had the smallest BIC.

A total of 14.8% of the population was excluded from the models due to insufficient BMI data (Figure 4.1). Soldiers excluded from the *traj* procedure were primarily junior enlisted with <4 service years (74.1% men, 78.8% women). Of the 122,794 Soldiers excluded from the *traj* procedure, 94,318 (76.8%) exited the Army in 2011 or entered the Army in 2014, leaving too little time to accumulate the ≥5 BMI observations required for final models.

GBTM does not model the intra-individual variability representing the non-trend portions of the trajectories (Frongillo & Rowe, 1999). To identify Soldiers with large intra-individual variability, such as BMI fluctuations caused by weight cycling, we fit person-specific growth curves to a random sample of 7,208 men and 7,069 women with ≥8 BMI observations. To determine the degree of BMI fluctuations over time, we obtained the root mean squares error (RMSE) from linear regression models of BMI with time specified as a quartic polynomial. Soldiers with a RMSE of ≥1.0 correspond to those with fluctuations of two or more BMI points, or about 4.5 kg, over the study period. Similarly to other research,(Field et al., 1999) we considered weight cycling to be ≥3 bidirectional changes of ≥2 BMI points as seen by visual inspection of graphs of BMI over time in Soldiers with an RMSE of ≥1.0.

Bivariate associations described the characteristics of individuals in the trajectory groups. Multinomial logistic regression using BMI trajectory as the dependent variable identified characteristics associated with trajectory membership. Race/ethnicity and marital status were simplified for regression models. Age categories used in the Army's weight allowance tables were used in regression models: 17-20 years, 21-27, 28-39, and ≥40. Due to Army age requirements, cross-classification of sociodemographics showed categories with few or no Soldiers (e.g. Soldiers ages 17-20 with >10 service years). These categories were collapsed to create a combined variable for age and service years.

In final models, rank and branch of service were removed since service years drives rank attainment and women were not in all branches.

Results

The overall trajectory showed for men at age 17 a mean BMI of 23.5 (SD 2.9) that gradually rose to 28.5 (SD 3.4), peaking at 43 years of age. BMI then declined with the mean BMI of men 61 years of age being 27.3 (SD 3.0) (Figure 4.2). For women 17 years of age, mean BMI was 23.8 (SD 2.1) with a small dip noticeable between 18 and 20 years of age, after which BMI began to gradually rise to 26.6 (SD 3.7), peaking at 41 years of age. BMI did not begin to decline until 48 years of age for women, with the mean BMI of women 61 years of age being 25.7 (SD 3.6) (Figure 4.2).

Final group trajectory models included 606,241 men and 98,091 women (Figure 4.3 and 4.4). Among men and women, we observed a BMI trajectory in which Soldiers gained BMI over time, which was labeled "increasing." The percentage of Soldiers in the increasing trajectory was about equal for men and women (11.1% and 10.6%, respectively). The trajectory with the largest percentage of Soldiers (60.6% men, 60.0% women) involved maintaining a consistent BMI over the time interval and was labeled "constant." A trajectory comprising those who lost BMI over time had the smallest percentage of Soldiers (7.2% men, 7.0% women), and was labeled "decreasing."

One BMI trajectory was substantially different in shape, but not proportion, between men and women, and was labeled "inconstant" (21.1% of men, 22.4% women). In men, the inconstant trajectory started at a higher mean BMI than the increasing and constant trajectories, but decreased to a lower point than all other trajectories in 2013. This decrease was followed by a gradual gain leaving the inconstant trajectory with a higher mean BMI in 2014 than in 2011. For women, the inconstant trajectory tended to be relatively flat towards the beginning and end of the time interval with an increase in BMI beginning in 2011 that peaked in 2013 and then declined leaving the mean BMI slightly higher in 2014 than in 2011.

With few exceptions, bivariate associations showed the characteristics of male and female Soldiers in all trajectories to be similar, with the increasing trajectory having primarily enlisted and married Soldiers with fewer service years (Table 4.2 and 4.3). The increasing trajectory also included the largest percentage of Soldiers who were MNR (13.6% men, 15.4% women), exceeded weight standards (29.4% men, 35.5% women), or had BMI fluctuations (29.4% men, 25.1% women). A larger percentage of women in the increasing trajectory were Black (42.8%). The constant trajectory included the smallest percentage of men and women who were MNR (3.0% men, 4.3% women), exceeded weight standards (16.3% men, 25.9% women), or had BMI fluctuations (4.1% men, 7.8% women). Men and women in the decreasing trajectory were older, had more service years and education, and were more commonly Officers and married.

In the multinomial logistic regression models, the reference group was the constant trajectory and Soldiers 17-20 years of age with any amount of service for the age related variables (Table 4.4 and 4.5). For men, increasing age and service years was related to a decreased risk of increasing trajectory membership. Men 21-27 years of age with <4 service years compared to the reference group, had 1.07 (95% CI 1.04-1.10) times lower risk of increasing trajectory membership relative to the constant trajectory. Men at ≥40 years of age with any service, compared to the reference group, had 1.56 (95% CI 1.49-1.61) times lower risk of increasing trajectory membership. Men ≥40 years of age with any amount of service in the decreasing trajectory had 2.12 (95% CI 2.01-2.23) times the risk decreasing trajectory membership relative to the constant trajectory. Higher education, compared to the high school/GED reference group, was associated with a decreased risk of increasing trajectory membership relative to the constant trajectory. Married men, compared to unmarried, were 1.97 (95% CI 1.93-2.01) times more likely to be in the increasing trajectory relative to the constant trajectory.

Unlike men, increasing age and service years was related to a higher risk of increasing trajectory membership in women. Women 21-27 years of age with <4 service years compared to the age and service reference group, had 1.08 (95% CI 1.01-1.15) times the risk of increasing trajectory membership relative to the constant trajectory. Women at ≥40 years of age with any service, compared to the reference group, had 1.77 (95% CI 1.61-1.94) times the risk of increasing trajectory membership. The risk gradient associated with age and service years was consistent in the increasing and inconstant, but not the decreasing trajectory. Women ≥40 years of age with any amount of service had 2.48 (95% CI 2.21-2.79) times the risk of decreasing trajectory membership relative to the constant trajectory. Higher education increased the risk of decreasing trajectory membership. Black and married women, compared to White and unmarried, were more likely to be in the increasing trajectory relative to the constant trajectory.

The analysis of intra-individual variability among 7,000 randomly selected Soldiers revealed that 6.4% of men and 12.8% of women had BMI fluctuations. Visual inspection of 40 randomly selected graphs of BMI over time in individuals with fluctuations showed evidence of weight cycling in 13 out of 20 graphs of men (65%) and 15 out of 20 graphs of women (75%) (Figure 6). If one were to extrapolate this analysis of the sample of 40 to the entire population of Soldiers and 45,366 (6.4%) of men in the Army were found to have BMI fluctuations, 29,488 would likely be weight cyclers, which equates to 4.2% of all male Soldiers. If 15,135 (12.8%) of female Soldiers were found to have BMI fluctuations, 11,351 would likely be weight cyclers, which equates to 9.6% of all female Soldiers.

Discussion

We established the overall BMI trajectory of U.S. Army Soldiers and found that BMI increased with age, similarly to but to a lesser degree than civilians. For male Soldiers, peak BMI was 28.5 in their forties, whereas the average civilian men's BMI peaks in their sixties, at 29.4 (Jackson et al., 2012a; National Center for Health Statistics (U.S.) & National Health and Nutrition Examination Survey (U.S.), 2016). For female Soldiers, peak BMI was 26.6 in their forties, whereas the average civilian woman's BMI peaks in their fifties at 30.2 (National Center for Health Statistics (U.S.) & National Health and Nutrition Examination Survey (U.S.), 2016). Differences between Soldiers' and civilians' peak BMI and the age at which BMI begins to decline are likely a result of factors related to military service.

Army weight regulations allow Soldiers' BMI and relative body fat to increase with age to a limited degree, (Friedl, 2012; United States Army, 2013) but Soldiers must continually self-monitor weight to avoid administrative actions for exceeding weight standards. Weight self-monitoring has been found to be a successful strategy for preventing weight gain among civilians (Burke, Wang, & Sevick, 2011). Soldiers who stay in the Army beyond initial obligations represent those able to self-manage weight, thus large increases in BMI are not as likely among career Soldiers, such as those in their forties.

Among civilians, declines in muscle mass contribute to downward trends in BMI with age, (Jackson, Janssen, Sui, Church, & Blair, 2012b). Soldiers may be more physically active than civilians, (T. J. Smith et al., 2012) but lean tissue decline associated with aging may also explain BMI decreases among Soldiers. Downward shifts in Army physical fitness standards with age support this theory. As Soldiers age, the number of repetitions of strength exercises required to pass physical fitness tests decreases, while the length of time allowed to pass cardiovascular fitness events increases (United States Army, 2012). Military-specific factors such as long-term weight self-monitoring, limits in weight gain, and greater physical activity are explanations for why Soldiers reach a lower peak BMI and at an earlier age. These factors, combined with normal lean tissue declines with age, may explain why the average Soldier's BMI declines sooner than the average civilian.

We identified four distinct BMI trajectory groups among Soldiers which supports our hypothesis of at least three distinct trajectories: constant, inconstant, and increasing. Our analysis also revealed a decreasing trajectory comprising the smallest percent of Soldiers. Military-specific and sociodemographic characteristics such as age, service years, MNR, and marriage were associated with BMI trajectory membership. We also found evidence of BMI fluctuations among Soldiers supporting our hypothesis that Soldier characteristics are associated with BMI trajectory, and that a small, but non-trivial number of Soldiers have fluctuations in BMI indicative of weight cycling.

Most Soldiers had a constant trajectory, reflecting adherence to weight control regulations. These Soldiers had the lowest mean BMI and fewer were MNR, exceeded weight standards, or had BMI fluctuations. Soldiers in the constant trajectory appear to be those most able to self-manage their weight. Intervention studies using self-monitoring techniques typically consist of small samples with larger studies enrolling a few thousand individuals (Burke et al., 2011). The military represents the largest known population consistently self-monitoring weight, thus adding to the evidence of self-monitoring as an effective weight management strategy.

Soldiers in the increasing trajectory had BMI gains, we postulate, were primarily of adipose tissue. The Army's physical training program relies on resistance training and running (United States Army, 2012). Studies in civilians on muscle changes in response to resistance training show gains in muscle and BMI after a 12-week program which is similar to the length of time Soldiers spend in basic combat training (BCT) where they begin physical training routines (Abe, DeHoyos, Pollock, & Garzarella, 2000; "Basic Combat Training," n.d.). Research on body composition changes in women after BCT show rapid gains in BMI due to fat-free mass increases (Friedl et al., 2001). In the increasing trajectory, BMI gains did not occur until >1 year into the study interval making BMI gains from increased muscularity unlikely.

In both men and women, the greatest percentage of Soldiers who exceeded weight standards, were MNR, or had BMI fluctuations were in the increasing trajectory. BMI fluctuations could be caused by weight gain only, but most graphs we inspected showed clear evidence of weight cycling. The increasing trajectory had the highest mean BMI and the largest percentage of Soldiers who were MNR. Studies have found a higher BMI associated with musculoskeletal injuries, (A. Anandacoomarasamy, Caterson, Sambrook, Fransen, & March, 2008; Knapik et al., 2007) which is a common cause of MNR among Soldiers.(A. D. Nelson & Kurina, 2013). Studies have also shown weight cycling to be predictive of future weight gain (Kroke et al., 2002; Saarni, Rissanen, Sarna, Koskenvuo, & Kaprio, 2006).

Married Soldiers had the highest risk of increasing trajectory membership which supports existing research associating marriage with weight gain (Sobal et al., 2003). For both men and women, degree attainment reduced the risk of increasing and inconstant trajectory membership, which concurs with research on the positive effects of education on BMI (A. K. Cohen, Rehkopf, Deardorff, & Abrams, 2013; McLaren, 2007). With the exception of more Black women in the increasing trajectory, we did not find race/ethnicity associated with group membership. This contradicts research that found an association between higher BMI in both genders of Black or Hispanic Soldiers (T. J. Smith et al., 2012).

To our knowledge, this is the first study to identify distinct BMI trajectories in a military population. We know of one study that used the same method to model BMI trajectories of veterans, but they did not center BMI resulting in a description of magnitude differences in BMI, not actual trajectories (Rosenberger et al., 2011). Strengths include the longitudinal design, size, and breadth of the dataset, which allowed for robust analysis with high statistical power. Adding to the credibility of trajectory models is the number of BMI observations and BMI measures taken during medical visits or in standardized Army events. A weakness was the limited years of observation time, but consistency since 2014 in body composition regulations allows conclusions to be applicable beyond the years studied. Nearly 15% of the sample was excluded from GBTM primarily because these Soldiers had fewer service years in which to accumulate BMI observations. Although the bivariate analysis did not indicate substantive differences in the characteristics studied, we acknowledge these Soldiers may have unique characteristics not captured here.

Conclusion

This study found four distinct BMI trajectories among Soldiers. These results show unique patterns in BMI among Soldiers who stay in the Army, adding to evidence of weight self-monitoring as an effective weight management technique. In civilian populations, workplace health programs incentivizing weight management may consider a formal self-monitoring component to increase action towards weight goals. In the Army, increasing the frequency of annual mandatory weight assessments may motivate Soldiers to maintain a weight that complies with regulations and minimizes weight fluctuations, which may help to improve the combat readiness of Soldiers. We also found important differences in Soldier characteristics associated with trajectory membership. Further investigation into the sociodemographic, military-specific characteristics, and gender-specific processes influencing BMI trajectories may help the Army better target resources aimed at improving Soldier health and combat readiness.

Table 4.1. Sources of data from the Stanford Military Data Repository used in the study.

Military Health System Data Repository
Medical diagnosis information
Defense Manpower Data Center
Sociodemographic and military service data
Comprehensive Ambulatory/Professional Encounter Record
Height, weight, BMI taken during healthcare encounters
Periodic Health Assessments
Height, weight, BMI taken during annual health exams
Digital Training Management System
Height, weight, BMI measured every six months at time of physical fitness tests
eProfile
Duty restrictions determined by medical provider

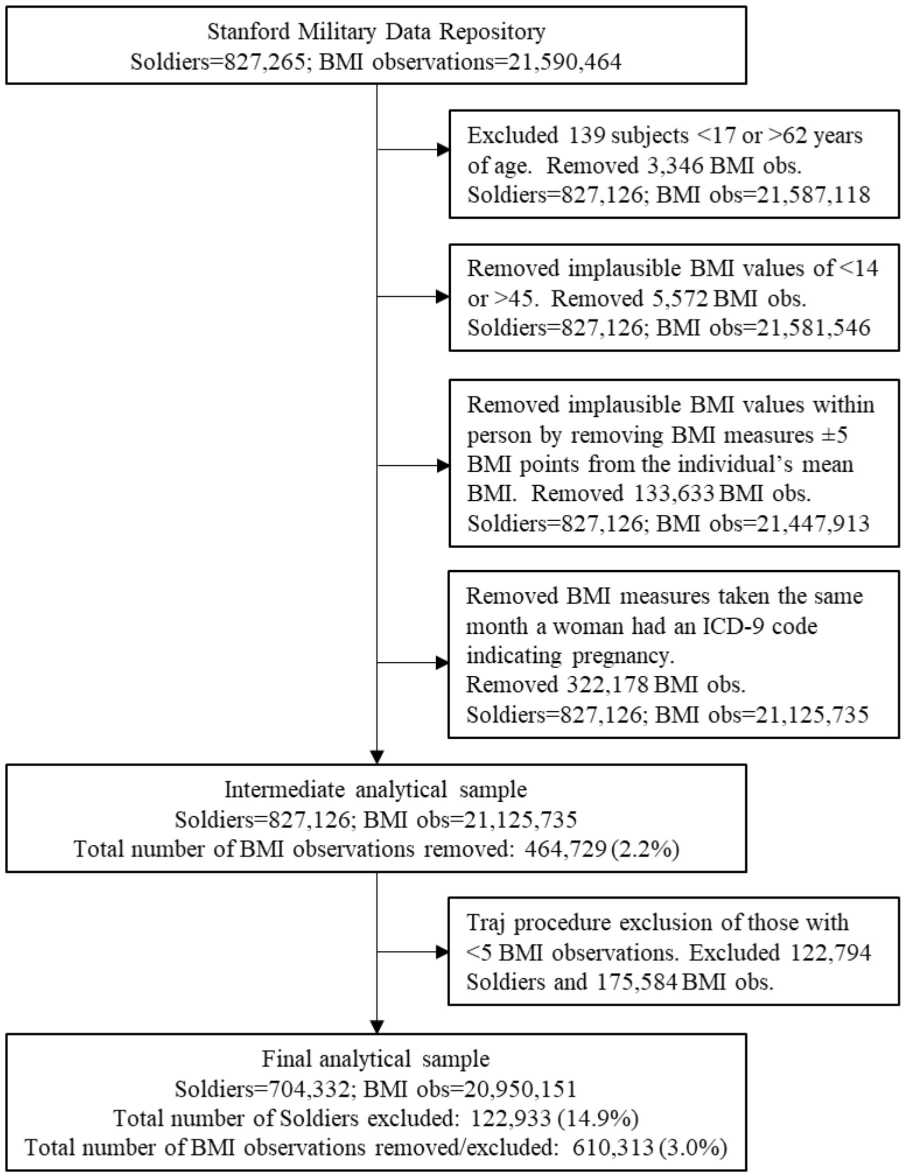

Figure 4.1. Flow diagram depicting development of analytical sample of Soldiers and BMI observations, Stanford Military Data Repository, 2011-2014.

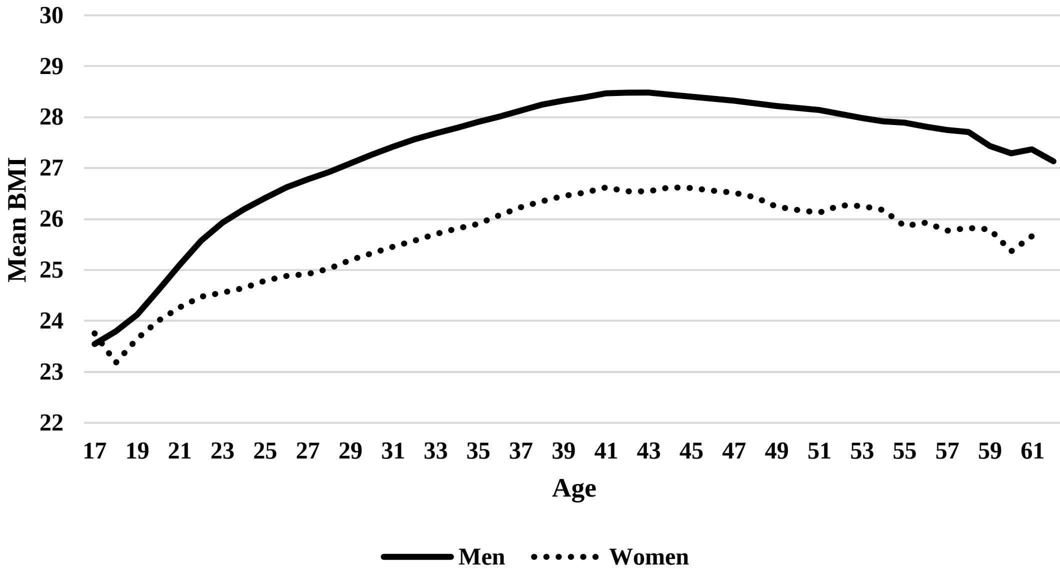

Figure 4.2. Mean BMI of male and female Soldiers ages 17-62, Stanford Military Data Repository, 2011-2014. Men = 708,884, Observations = 18,256,225; Women = 118,242, Observations = 2,869,510. Note: Standard error at each year of age ranged from 0.003 – 0.470.

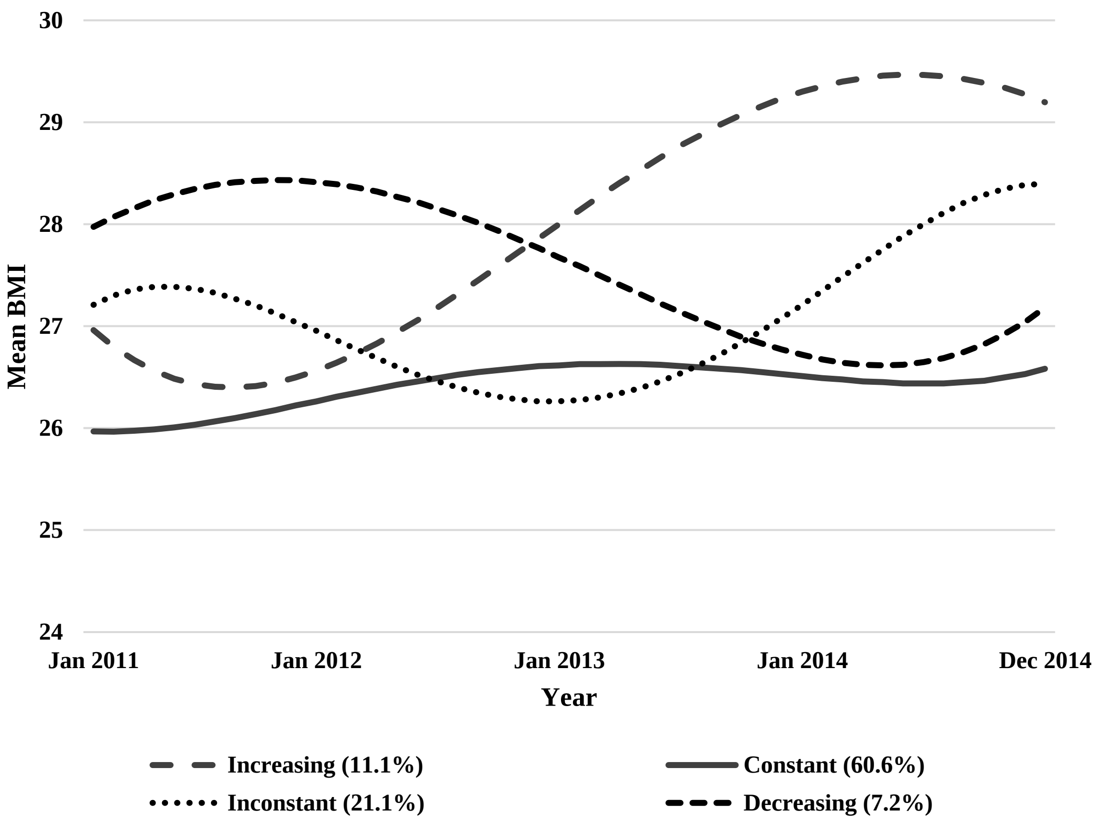

Figure 4.3 BMI trajectories of male Soldiers, Stanford Military Data Repository, 2011-2014. Soldiers = 606,241, Observations = 18,113,713.

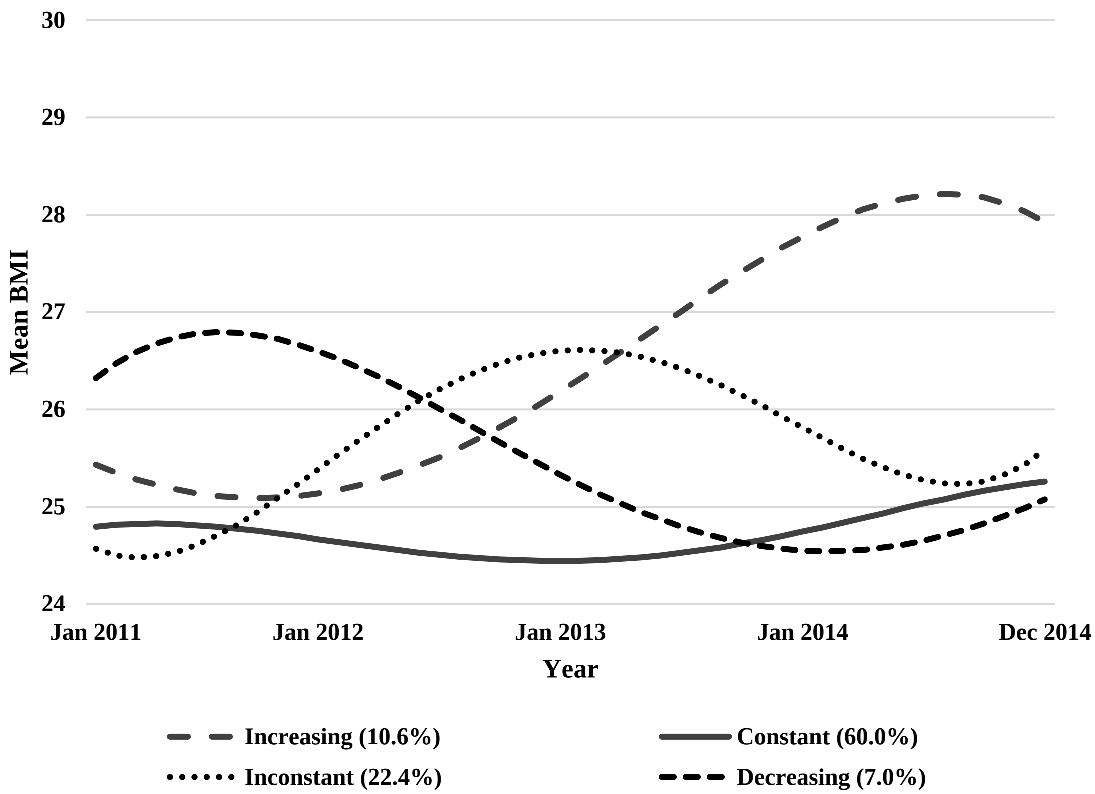

Figure 4.4 BMI trajectories of female Soldiers, Stanford Military Data Repository, 2011-2014. Soldiers = 98,091, Observations = 2,836,438.

Table 4.2. Characteristics of male Soldiers by BMI trajectory, Stanford Military Data Repository, 2011-2014.

Sociodemographic variables, mean (SD) or %	**Increasing 11.1% n=66,317 obs=2,545,037**	**Constant 60.6% n=380,085 obs=10,084,005**	**Inconstant 21.1% n=118,135 obs=3,791,959**	**Decreasing 7.2% n=41,704 obs=1,692,712**	**Excluded 14.5%[a] n=102,643 obs=144,975**
Mean BMI	28.0(3.5)	26.4(3.5)	27.1(3.4)	27.5(3.3)	25.9(3.9)
Age(y), first obs.	26.9(7.0)	27.5(7.7)	27.2(7.5)	30.5(7.6)	24.5(6.7)
Rank categories[b]					
E1-E4	62.5	58.9	60.5	36.6	80.1
E5-E9	28.2	25.6	26.9	39.4	13.8
W1- O10	9.3	15.4	12.5	24.0	6.1
Years in Service					
Less than 4	56.7	57.1	57.1	34.8	74.1
4-10	22.4	19.9	20.2	26.3	16.4
11-18	14.3	13.4	14.3	26.3	3.9
18 or more	6.7	9.6	8.4	12.6	5.6
Marital Status					
Married	74.2	62.7	68.0	82.4	32.4
Single	24.3	35.4	30.3	15.9	65.5
Divorced/ Widowed	1.6	1.9	1.7	1.7	2.1
Education Level					
High School/GED	82.1	75.4	78.9	66.1	85.0
Some College	8.1	8.4	8.1	10.6	5.4
Bachelors	7.2	11.3	9.2	14.7	7.6
Graduate	2.6	4.9	3.8	8.5	2.0
Race/Ethnicity					
NH White	62.9	64.0	62.7	62.7	66.1
NH Black	18.8	17.7	18.3	17.7	15.7
NH Asian/ Pacific Islander	2.8	3.7	3.2	3.3	3.7
Multi-Racial	1.9	2.4	2.5	3.7	1.9
American Indian/ Alaskan Native	0.8	0.6	0.6	0.5	0.8
Hispanic	11.8	12.4	11.5	12.1	11.8
Branch of Army					
Combat Arms	44.9	47.3	46.0	42.0	51.4
Combat Support	40.2	36.7	38.3	38.9	35.2
Combat Service Support	14.9	16.0	15.7	19.1	13.4
Medically Not Ready	13.6	3.0	5.9	6.0	0.1
Exceed weight standards	29.4	16.3	23.8	19.3	23.7
BMI fluctuations (RMSE ≥1.0)	12.2	4.1	7.9	10.3	-
BMI Obs.	38.4(8.9)	26.5(14.1)	32.1(11.4)	40.6(7.6)	1.4(1.5)

[a]Percent of total sample of men (n=708,884); [b]Enlisted ranks: E1-E9; Officer ranks: W1-O10; NH=non-Hispanic.

Table 4.3. Characteristics of female Soldiers by BMI trajectory, Stanford Military Data Repository, 2011-2014.

Sociodemographic variables, mean (SD) or %	**Increasing 10.6% n=10,215 obs= 407,894**	**Constant 60.0% n=61,647 obs=1,550,747**	**Inconstant 22.4% n=19,674 obs=603,980**	**Decreasing 7.0% n=6,555 obs=273,81**	**Excluded 17.0%[a] n=20,151 obs=30,609**
Mean BMI	26.5(3.1)	24.7(3.2)	25.7(3.4)	25.5(3.2)	24.5(3.4)
Age(y), first obs.	28.3(7.6)	26.8(7.6)	27.4(7.6)	29.4(7.6)	23.8(6.0)
Rank categories[b]					
E1-E4	54.1	61.8	60.2	43.2	81.0
E5-E9	30.4	19.9	22.9	31.5	10.4
W1- O10	15.6	18.3	16.9	25.3	8.6
Years in Service					
Less than 4	52.2	63.8	59.7	44.6	78.8
4-10	22.3	18.9	20.3	25.1	14.8
11-18	18.1	10.4	12.7	22.1	3.6
18 or more	7.4	6.9	7.3	8.2	2.8
Marital Status					
Married	66.1	56.4	60.5	67.6	38.5
Single	25.6	37.1	32.1	24.3	56.9
Divorced/ Widowed	8.3	6.5	7.4	8.1	4.6
Education Level					
High School/GED	69.5	69.0	70.2	61.4	80.0
Some College	10.8	9.0	9.7	10.8	6.8
Bachelors	13.8	14.9	13.9	18.1	9.8
Graduate	5.9	7.1	6.2	9.8	3.3
Race/Ethnicity					
NH White	36.9	43.4	41.9	41.5	48.3
NH Black	42.8	34.0	35.9	34.9	31.0
NH Asian/ Pacific Islander	3.6	4.9	4.3	4.5	3.8
Multi-Racial	4.1	3.6	3.9	4.3	2.9
American Indian/ Alaskan Native	0.9	1.0	0.8	0.9	1.1
Hispanic	11.8	13.1	13.2	13.9	12.8
Branch of Army					
Combat Arms	0.0	0.0	0.0	0.0	0.0
Combat Support	28.6	33.3	45.5	50.0	0.0
Combat Service Support	71.4	66.7	54.6	50.0	100.0
Medically Not Ready	15.4	4.3	5.5	8.5	0.1
Exceed weight standards	35.5	25.9	29.3	28.5	33.1
BMI fluctuations (RMSE ≥1.0)	25.1	7.8	18.8	17.7	-
BMI Obs.	40.0(8.5)	25.2(14.9)	30.7(12.2)	41.8(7.3)	1.5(1.4)

[a]Percent of total sample of women (n=118,242); [b]Enlisted ranks: E1-E9; Officer ranks: W1-O10; NH=non-Hispanic.

Table 4.4. Relative risk ratios and 95% confidence intervals from multinomial logistic regression of characteristics of male Soldiers by BMI trajectory, Stanford Military Data Repository, 2011-2014.

Sociodemographic variables	**Relative Risk Ratios [95% CI]**		
	Increasing	**Inconstant**	**Decreasing**
Age (y) Service (y)			
17-20 all service	Ref.	Ref.	Ref.
21-27 <4 years	0.931 [0.908, 0.955]	0.897 [0.879, 0.914]	1.403 [1.343, 1.463]
21-27 >4 years	0.932 [0.902, 0.962]	0.860 [0.838, 0.883]	2.094 [1.994, 2.199]
28-39 <4 years	0.811 [0.779, 0.845]	0.845 [0.818, 0.873]	1.568 [1.480, 1.662]
28-39 >4 years	0.809 [0.786, 0.833]	0.865 [0.846, 0.885]	2.806 [2.686, 2.930]
>40 all service	0.642 [0.617, 0.669]	0.784 [0.760, 0.808]	2.119 [2.013, 2.230]
Education Level			
High School/GED	Ref.	Ref.	Ref.
Some College	0.873 [0.846, 0.901]	0.921 [0.899, 0.944]	1.082 [1.045, 1.121]
Bachelors	0.613 [0.594, 0.633]	0.797 [0.778, 0.815]	1.208 [1.171, 1.246]
Graduate	0.520 [0.493, 0.548]	0.754 [0.727, 0.782]	1.329 [1.275, 1.397]
Race/Ethnicity			
NH White	Ref.	Ref.	Ref.
NH Black	1.074 [1.051, 1.098]	1.045 [1.027, 1.063]	0.997 [0.970, 1.025]
NH Other	0.958 [0.924, 0.994]	0.990 [0.963, 1.018]	1.027 [0.985, 1.070]
Hispanic	1.037 [1.011, 1.065]	1.091 [1.069, 1.113]	1.089 [1.054, 1.125]
Marital Status			
Unmarried	Ref.	Ref.	Ref.
Married	1.966 [1.926, 2.008]	1.374 [1.352, 1.395]	1.904 [1.850, 1.960]

Note: Reference: Constant trajectory

Table 4.5. Relative risk ratios and 95% confidence intervals from multinomial logistic regression of characteristics of female Soldiers by BMI trajectory, Stanford Military Data Repository, 2011-2014.

Sociodemographic variables	Relative Risk Ratios [95% CI]		
	Increasing	**Inconstant**	**Decreasing**
Age (y) Service (y)			
17-20 all service	Ref.	Ref.	Ref.
21-27 <4 years	1.077 [1.007, 1.152]	1.110 [1.058, 1.164]	1.439 [1.311, 1.580]
21-27 >4 years	1.380 [1.269, 1.501]	1.205 [1.131, 1.283]	2.160 [1.936, 2.409]
28-39 <4 years	1.504 [1.370, 1.652]	1.241 [1.156, 1.332]	1.661 [1.465, 1.885]
28-39 >4 years	2.002 [1.864, 2.151]	1.377 [1.303, 1.456]	3.223 [2.929, 3.547]
>40 all service	1.766 [1.610, 1.937]	1.376 [1.281, 1.479]	2.482 [2.205, 2.794]
Education Level			
High School/GED	Ref.	Ref.	Ref.
Some College	0.939 [0.874, 1.010]	0.944 [0.891, 1.001]	0.989 [0.905, 1.080]
Bachelors	0.789 [0.739, 0.842]	0.852 [0.811, 0.895]	1.078 [1.002, 1.160]
Graduate	0.606 [0.550, 0.668]	0.733 [0.682, 0.789]	1.036 [0.938, 1.145]
Race/Ethnicity			
NH White	Ref.	Ref.	Ref.
NH Black	1.388 [1.323, 1.457]	1.062 [1.023, 1.102]	1.016 [0.957, 1.079]
NH Other	1.005 [0.927, 1.091]	0.961 [0.904, 1.021]	1.009 [0.920, 1.107]
Hispanic	1.004 [0.935, 1.079]	1.018 [0.967, 1.072]	1.113 [1.026, 1.208]
Marital Status			
Unmarried	Ref.	Ref.	Ref.
Married	1.449 [1.385, 1.516]	1.154 [1.116, 1.193]	1.420 [1.343, 1.501]

Note: Reference: Constant trajectory

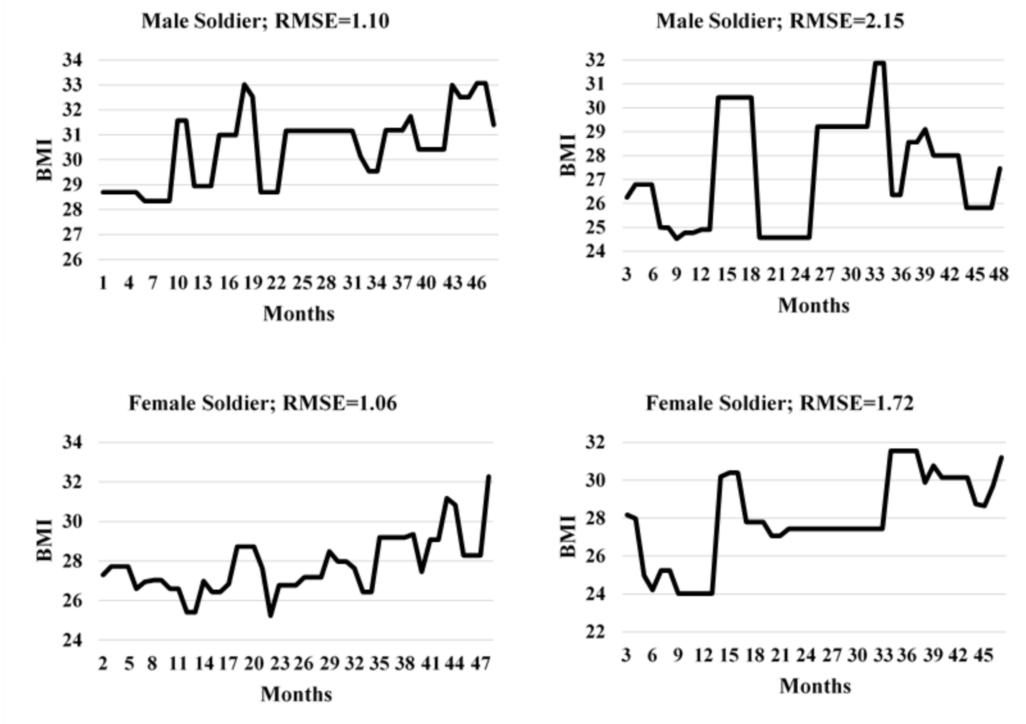

Figure 4.5 Examples of weight cycling in Soldiers with a root mean sqared error (RMSE) of ≥1.0, Stanford Military Data Repository, 2011-2014.

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4.2 Manuscript 2

STRESSFUL LIFE CHANGES AND THEIR RELATIONSHIP TO NUTRITION-RELATED HEALTH OUTCOMES AMONG U.S. ARMY SOLDIERS[1]

[1]Jayne, J.M., Blake, C.E., Frongillo, E.A., Liese, A.D., Cai, B., Nelson, D. A., Kurina, L.M., Funderburk, L. To be submitted to *American Journal of Health Promotion*.

Abstract

Stressful life changes such as marital transitions or relocation may tax the adaptive capacity of individuals placing them at risk for undesirable health outcomes. Some stressful life changes are normal life-course occurrences, but Soldiers experience a greater number of stressful life changes due to military service. Using longitudinal data from the Stanford Military Data Repository representing all active-duty U.S. Army Soldiers who were age 17-62 between 2011 and 2014 (n=827,126), we aimed to determine if experiencing stressful life changes was associated with blood pressure changes or an earlier onset of hyperlipidemia diagnosis, substantial weight gain, or being separated from the Army for failure to meet body composition standards. We also aimed to determine which stressful life changes were most associated with these outcomes and if there were gender differences in the magnitude of the associations. Event history analysis was used to model associations with outcomes being considered non-repeatable or repeatable and modeled as a one-way or two-way transition. Marriage raised odds of substantial weight gain three months later by 1.23 times for men and 1.68 times for women with women having higher cumulative risk of weight gain in the 12 months following marriage. Relocation was associated with lower blood pressure in men and women, but raised odds of substantial weight gain in women. Developing a physical duty limitation raised odds of hyperlipidemia two months later by 1.42 times for men and 1.83 times for women and the odds of substantial weight gain two months later by 3.16 times in men and 1.68 times in women. The short intervals between observations contribute novel information regarding stressful life changes and disease development that are applicable to military and civilian populations. Utilizing this information could help the Army employ existing resources to mitigate the effects of stress on health.

Key words: Stress; military; event history analysis; hyperlipidemia; weight gain; women

Introduction

Stress is ubiquitous across the human experience. Defined as an imbalance between life's demands and an individual's ability to adapt to them, stress can lead to physiological and behavioral changes that increase disease risk (S. Cohen et al., 1995; Mustacchi, 1990; Spruill, 2010; Peggy A. Thoits, 1983). Examples of exposures that can tax the adaptive capacity of individuals are stressful life changes (Dohrenwend et al., 1978; Sarason et al., 1978). Stressful life changes include divorce, relocation, changing jobs, or illness, (Dohrenwend et al., 1978; Sarason et al., 1978) but even life changes that are typically viewed as desirable, such as marriage, can be stressful due to the adaptations required to meet the challenges of changing roles and responsibilities (Dohrenwend & Dohrenwend, 1974; Kaplan, 1983; Sarason et al., 1978). While no life change can be classified as universally stressful to all individuals, (Cassel, 1976; Krantz et al., 1985) some life changes are more likely to tax the adaptive capacity of individuals, particularly when changes are clustered, chronic, and complex (Abood & Milton, 1988; Dohrenwend et al., 1978; Dohrenwend & Dohrenwend, 1974; Hammen, 2005; Holmes & Rahe, 1967; Johnston & Wallace, 1990; Sarason et al., 1978; Steptoe, 1991; Peggy A. Thoits, 1983).

Stress has been implicated as a contributor to health conditions such as obesity, hypertension, and hyperlipidemia (Black, 2003; Kivimäki et al., 2002; Lagraauw et al., 2015; Stoney, Bausserman, et al., 1999; Stoney, Niaura, et al., 1999). Stressful experiences may prompt individuals to turn to unhealthy eating behaviors as coping strategies (Holton et al., 2016; Laugero et al., 2011) and greater perceived stress is associated with increased sweet and snack consumption, lower physical activity, and weight gain (Block et al., 2009; Laugero et al., 2011; Proper et al., 2013). Stress can influence the physiology by directly affecting the body's regulatory systems, increasing blood pressure, heart rate, and inflammation (Lagraauw et al., 2015). Results of the physiological stress response, particularly when stress is chronic, includes higher risk of hypertension, (Mustacchi, 1990; Spruill, 2010) accelerated atherosclerosis, and cardiovascular disease (Lagraauw et al., 2015; McEwen & Stellar, 1993).

Members of the military deal with many of the same stressful life changes as civilians, including marriage, divorce, relocation, childbirth, and job change, but in the context of military life. Soldiers experience additional stressful life changes such as being deployed to a combat zone, and reintegrating from deployment, while bearing the same responsibilities for childcare, education, parenting, and career management as civilians (Drummet et al., 2003). For women, balancing these responsibilities can be especially challenging considering that female Soldiers remain the primary caregiver and caretaker of the family (Wahl & Randall, 1996). Frequent changes when combined with multiple roles, responsibilities, and demands of Army service may compound the total cumulative stress load that normally occurs over an individual's life-course, putting Soldiers at risk for stress-related health conditions.

Enlisted military service consistently ranks as one of the most stressful professions based on criteria such as workplace hazards, physical demands, deadlines, and environmental conditions ("The Most Stressful Jobs of 2018," n.d.). Soldiers must meet physical fitness requirements, be in compliance with weight and body composition standards, and remain free of major physical limitations to remain in service (United States Army, 2013; United States Army, 2016b). Considering that the negative health consequences of chronic stress may impact the ability of Soldiers to meet these requirements (Hammen, 2005; Krantz et al., 1985; Lydeard & Jones, 1989) and that enlisted military personnel have highly stressful jobs and comprise 82% of the Army's total force (371,874 Soldiers) ("Military Careers," n.d.), there is a salient need to investigate the impact of stress on Soldier health. Little research is available on the association between stressful life changes among Soldiers, (Bedno et al., 2014; Granado et al., 2009) which stressful life changes are most concerning, and how the timing of stressful life changes affects the development of nutrition-related health outcomes.

In this prospective cohort study of the entire United States Army population over a four-year period, we aimed to determine if experiencing stressful life changes is associated with (1) a change in blood pressure or (2) an earlier onset of hyperlipidemia diagnosis, substantial weight gain, or being separated from the Army for failure to meet body composition standards. We also aimed to determine which stressful life changes were most associated with these outcomes and if there were differences in associations between men and women, hypothesizing that for the outcomes of hyperlipidemia and substantial weight gain, the most stressful life changes would be marital transitions, relocation, and becoming medically not ready (MNR) for deployment and that there would be gender differences in the magnitude of the associations.

Methods

Data and study population

Data were from the Stanford Military Data Repository (SMDR), a de-identified longitudinal dataset encompassing health, administrative, and sociodemographic data from all active-duty Soldiers between January 2011 and December 2014. The SMDR was created by merging data from multiple military data systems. Medical diagnosis information came from the Military Health System Data Repository (MDR). Sociodemographic data such as marital status arose from the Defense Manpower Data Center (DMDC). Weight measures were from the Comprehensive Ambulatory/Professional Encounter Record (CAPER), Periodic Health Assessments (PHA), and Digital Training Management System (DTMS), the latter of which captured data from the semi-annual Army Physical Fitness Test. Physical limitation data came from eProfile, the tracking system for Soldiers with a medical limitation to duty. These data were organized as a person-month-based panel providing up to 48 months of observation. The sample was restricted to Soldiers 17-62 years old (n=827,126), which is the typical age range of Soldiers due to minimum entrance and mandatory retirement rules. The study was approved by the University of South Carolina and the Stanford University institutional review boards and the Defense Health Agency's Human Research Protection Office.

Nutrition-related health outcomes

Study outcomes were changes in systolic blood pressure (mm Hg), diagnosis of hyperlipidemia, substantial weight gain, and separation from the Army for failing to meet body composition standards. Blood pressure is an average of any systolic blood pressure measured in a given month by trained medical staff such as nurses or heath technicians at military medical facilities. Diagnosis of hyperlipidemia was determined by the presence of an International Classification of Diseases (ICD)-9 code for hyperlipidemia/dyslipidemia in a Soldier’s outpatient medical record. Weight was measured by trained medical staff such as nurses or heath technicians at military medical facilities or by trained non-commissioned officers during mandatory body composition checks. Weight observations were screened for biologically implausible values within the population and within each person's data by subtracting each Soldier's mean weight from all of their available weight observations. Weight measures varying ±11.5 kg (which equates to about 5 BMI points) from the person's mean were considered implausible values. This rule permitted any two weight observations to be approximately 23 kg apart before a value was considered biologically implausible within a person's data. In women, weight observations taken in a month when an ICD-9 code for pregnancy was found in the medical record were removed. These cleaning procedures removed 54,842 weight observations or 0.25% of the total. Substantial weight gain occurred if a Soldier's weight exceeded their first observed weight by ≥10% over the study period. Separation from the Army for failing to meet body composition standards applies to Soldiers whose inability to meet body composition requirements is the sole basis of their separation and was determined by a chapter 18 separation code in the Soldiers' personnel records (United States Army, 2016a).

Exposure variables

Exposure variables were stressful life changes: changes in marital status, becoming deployed to a combat zone (or returning from deployment), relocation, adding a child, change in rank, change in military occupation, or development of a physical limitation to duty. Changes in marital status, number of children, relocation, rank, and occupation were determined from personnel records. Change in marital status occurred if a Soldier became single through any means (e.g. divorced) or became married. A Soldier could have added a child either by adoption or birth. Relocation was determined by a change in duty station based on zip code. Change in rank could be achieved by promotion or demotion. Change in occupation was determined by a change in military job code. Deployment was based on personnel records indicating the Soldier had been deployed to a combat zone. Physical duty limitations were determined if a Soldier was medically not ready (MNR) for deployment by a code of 3 or 4 indicating a substantial duty limitation in one or more categories used to quantify medical readiness in the eProfile system: physical capacity, upper extremities, lower extremities, or psychiatric (United States Army, 2016b). MNR is akin to a serious injury or illness in civilians.

Risk Period

The risk period was the period of time in which it is conceivable for the occurrence of a stressful life change to have affected behavioral and physiological paths leading to the development of a study outcome. The risk period for each outcome was based on the available literature taking into account Army regulations and structural factors, such as those related to separating a Soldier from service. We considered the risk period for blood pressure to be concurrent with the occurrence of the stressful life change since blood pressure is labile in response to stress (Black & Garbutt, 2002; Mustacchi, 1990). The risk period for hyperlipidemia was 3-6 months prior to diagnosis of hyperlipidemia due to the length of time necessary for hyperlipidemia to develop (Stoney, Niaura, et al., 1999; Tang et al., 1998). The risk period for substantial weight gain was 7-12 months before the ≥10% weight gain threshold had been reached and was based on the amount of time weight gain can occur, (Helander et al., 2016) considering that in the Army weight gain is discouraged (United States Army, 2013). Risk period for separation from the Army was 10-18 months before separation based on Army procedures for separating Soldiers from service (United States Army, 2013; United States Army, 2016a).

Sociodemographic and control variables

Rank, marital status, branch of Army, and number of children were used in descriptive tables. Branch of Army (combat, combat support, combat service support) was used descriptively but not as a control variable since women were not in all branches. Time-varying control variables were years of service, age, and education level. The only time invariant control variable was race/ethnicity. Race and ethnicity were separate variables and were combined using federal guidelines (Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian/Pacific Islander, Multi-Racial, American Indian/Alaskan Native, Hispanic) ("OMB Directive 15: Race and Ethnic Standards for Federal Statistics and Administrative Reporting," n.d.).

Statistical Analysis

Data were analyzed using Stata, version 14.2 (StataCorp, College Station, TX). All analyses were stratified by gender given expected differences in the associations of stress between men and women (Liu & Umberson, 2015; Udo et al., 2014). The significance level was set as p-value < 0.01. Event history analysis was used to model the association of stressful life changes with study outcomes (Yamaguchi, 1991). Nutrition-related health outcomes were non-repeatable or repeatable, modeled as a one-way or two-way transition, respectively. Non-repeatable outcomes of hyperlipidemia, substantial weight gain, and separation from the Army for failure to meet body composition standards were analyzed using discrete-time logit models of a non-repeatable one-way transition. The outcome data were constructed such that once a non-repeatable event occurred, an individual's subsequent data were not included. Blood pressure was considered a repeatable outcome and was analyzed using a discrete-time regression model of a repeatable two-way transition. Models were estimated using the robust cluster variance estimator.

Two of the stressful life changes, change in marital status and deployment, involved a change in status, e.g., being married or single or being deployed or not deployed. For these status variables, we used a variable that reflected their status at any given month and lagged variables that reflected their status in the month(s) prior to identify those who had a change in status. Additionally, we examined interactions between lagged and current status variables to differentiate the effect of transitions from one status to another (e.g. the change from married to single versus the transition from single to married). We also created lagged variables for the outcome of blood pressure to account for blood pressure at an observation the month before. This meant that Soldiers were required to have at least two blood pressure measures taken in consecutive months to be included in the analysis. The mean number of blood pressure measures in those with consecutive measures was 8.97 (SD=4.37, range 2-41, skew: 0.83, kurt: 3.93) in men and 12.35 (SD=5.5, range 2-40; skew: 0.46, kurt: 3.00) in women. Due to the requirement of consecutive measures and the possible influence of Soldiers with more blood pressure measures on estimates, we examined differences in mean blood pressure between those included and those excluded in final models. The mean blood pressure of men included and excluded was 125.1 (SD=11.5) and 123.0 (SD=11.9), respectively. The mean blood pressure of women included and excluded was 117.1 (SD=11.4) and 123.7 (SD=11.8), respectively.

Using the hypothesized risk period, models of hyperlipidemia and substantial weight gain were tested in two month increments prior to the event (e.g. 1-2 months prior, 2-3, months prior), with individual stressful life changes, lagged variables, interactions, and controls, using the data to confirm the two-month interval of highest odds. Out of this two-month interval, each of these months were then tested separately with the month closest to the event being chosen if the regression coefficients were not appreciably different, to best represent the month when the event developed. Models of separation for body composition failure were narrowed to an 11-month period where estimates showed the largest coefficient. Adding a child was not included in models of substantial weight gain in women due to the influence of pregnancy on weight gain, which is a desirable occurrence during pregnancy. Occupation change was not included as an exposure variable in models of women due to the small number of women who changed military occupations.

Model fit was assessed by comparing statistical significance and the root mean squared error (RMSE) or the area under the receiver operating characteristic (ROC) curve to assess model prediction and discrimination for logit models. Final models presented are of the outcome at the month(s) where the effect of the stressful life changes were greatest, controls, and the fewest number of lagged variables and interactions found to contribute to model fit. For odds ratios less than one, the inverse association was calculated and reported in the discussion to aid interpretation (e.g., an odds ratio of 0.80 equates to 1.25 lower odds). A *z* test was used to test differences between men and women since models were stratified by gender. The *z* test result is equivalent to including gender as an interaction term in models not stratified.

Since the main models estimate the association of an exposure on an outcome at a specific month, we also examined the survival functions for substantial weight gain for those who became married compared to those who did not over a 12-month period. The coefficients from a sequence of models over 12 months were used to calculate the hazard and survival function at each month, and then the cumulative probability of weight gain in men and women at each month after marriage occurred (Yamaguchi, 1991). The difference in cumulative probability of weight gain over 12 months was found by subtracting the probability of weight gain in those who married from the probability of weight gain in those who did not marry.

Results

During the study period, mean systolic blood pressure was 125.4 mmHg (SD=11.6) and 117.1 mmHg (SD=11.3) for men and women, respectively (Table 4.6). Six percent of men and nearly 3% women had a hyperlipidemia diagnosis. Over 22% of men and 39% of women had substantial weight gain and less than 1% (n=6,410) of Soldiers were discharged for failure to meet body composition standards. For exposure variables, 36% of men and 33% of women experienced a rank change, 67% of men and 51% of women experienced deployment, about 64% of men and women relocated, 19% of men and 26% of women experienced a marital transition, 7% of men changed occupation, 4% of men and 5% of women developed a physical limitation to duty, and 26% of men and 21% of women added a child during the study period. The mean age of the population was about 29 years (SD=8.0 men, 8.1 women). Most Soldiers were enlisted (86% men, 83% women), had less than 10 years of service (70% men, 75% women), were married (58% men, 49% women), had no children (52% men, 62%

women), had a high school education/GED (69% men, 60% women), and were White (64% men, 44% women).

In models of blood pressure, referring to significant regression coefficients, becoming married was associated with an increase of 0.49 mm in blood pressure in men (Table 4.7). Relocation was associated with a decrease of 1.35 and 1.32 mm in blood pressure for men and women, respectively (difference between genders, $z = 0.15$, $p = 0.88$). Adding a child was associated with a 2.47 mm increase in blood pressure in women. Rank change was associated with a 0.47 mm increase in blood pressure in men. Change in occupation was associated with a 0.79 mm decrease in blood pressure in men. Becoming MNR was associated with a 1.24 mm increase in blood pressure in men.

In models of hyperlipidemia, deployment lowered the odds of a hyperlipidemia diagnosis seven months later by 2.22 times for men and 3.70 times for women compared to those who did not deploy (difference between genders, $z = 1.29$, $p = 0.20$ (Table 4.8). Returning from deployment raised the odds of a hyperlipidemia diagnosis seven months later by 1.11 times for men. Relocation raised the odds of a hyperlipidemia diagnosis two months later by 1.20 times for men compared to those who did not relocate. Adding a child raised the odds of a hyperlipidemia diagnosis two months later by 1.50 times for women compared to those who did not add a child. Becoming MNR raised the odds of a hyperlipidemia diagnosis two months later by 1.42 times for men and 1.83 times for women compared to those who did not become MNR (difference between genders, $z = 0.79$, $p = 0.43$).

In models of substantial weight gain, becoming married raised the odds of a substantial weight gain three months later by 1.23 times for men and 1.68 times for women compared to those who did not get married (difference between genders, $z = 4.70$, $p<0.001$) (Table 4.9). Becoming single lowered the odds of a substantial weight gain three months later by 1.25 times for women compared to those who did not become single. Deployment raised the odds of substantial weight gain 12 months later by 1.19 times for men compared to those who did not deploy. Returning from deployment lowered the odds of substantial weight gain 12 months later by 1.10 times for men. Relocation lowered the odds of substantial weight gain eight months later by 1.11 times for men, but raised the odds of substantial weight gain eight months later for women by 1.16 times, compared to those who did not relocate (difference between genders, $z = 6.96$, $p<0.001$). Adding a child raised the odds of substantial weight gain eight months later by 1.06 times for men compared to those who did not add a child. Rank change lowered the odds of substantial weight gain 11 months later by 1.05 times for men compared to those who did not change rank. Becoming MNR raised the odds of a substantial weight gain two months later by 3.16 times for men and 1.68 times for women compared to those who did not become MNR (difference between genders, $z = 0.79$, $p = 0.43$).

In models of separation for failure to meet body composition standards, deployment lowered the odds of separation 13-24 months later by 1.19 times for men compared to those who did not deploy (Table 4.10). Adding a child raised the odds of separation for failure to meet body composition standards 1-12 months later by 1.22 times for men compared to those who did not add a child. Change in rank lowered the odds of separation for failure to meet body composition standards 4-15 months later by 2.94 times for men and 3.13 times for women compared to those who did not change rank (difference between genders, $z = 0.34$, $p = 0.73$). Change in occupation lowered the odds of substantial weight gain 10-21 months later by 1.61 times for men compared to those who did not change occupation. Becoming MNR lowered the odds of separation for failure to meet body composition standards 10-21 months later by 4.76 times for men compared to those who did become MNR.

The analysis of weight gain in the 12 months following marriage showed an increase in the probability of having substantial weight gain every month after marriage with the increase being more pronounced in women than men (Figure 4.6). Women who got married had a 0.117 difference in probability of weight gain 12 months later compared to women who did not marry. In men who got married, there was a 0.028 difference in probability of weight gain 12 months later compared to those who did not marry.

Discussion

Findings support the hypothesis that marital transitions and becoming MNR raised the odds of hyperlipidemia diagnosis and substantial weight gain and that there were gender differences in the magnitude of the associations. Associations were mixed for relocation. Relocation was associated with a decrease in blood pressure for both genders, raised odds of hyperlipidemia in men, lower odds of substantial weight gain in men, but raised odds in women.

Marital transitions can affect health through the stress resulting from shifting roles and responsibilities in addition to behavior changes resulting from these adaptations (Sarason et al., 1978; Sobal et al., 2003). Marriage was associated with modest effects on blood pressure in men, possibly because of the labile nature of blood pressure and measures being taken too distally to the exposure for larger associations with blood pressure to be observed. Becoming married was associated with raised odds of substantial weight gain three months later in both men and women, with the cumulative probability increasing every month in the year after marriage with a bigger magnitude in women. The increase in magnitude seen in women could be the result of a rebound effect of dieting behaviors prior to marriage (Neighbors & Sobal, 2008) or due to role changes influencing eating behaviors (Neighbors & Sobal, 2008). Becoming single was associated with lower odds of weight gain in women. Our results are consistent with existing research on marital transitions and weight change as well as differences between men and women, (Neighbors & Sobal, 2008; Rauschenbach, Sobal, & Frongillo, 1995; Wilson, 2012) but unlike other studies, these results point to a specific time point at which weight gain odds were highest and show the cumulative probability of weight gain in women steadily increasing in the 12 months following marriage, when compared to women who did not marry.

Deployment involves being physically located in a combat zone for a prolonged period of time (Committee on the Assessment of the Readjustment Needs of Military Personnel, Populations, & Medicine, 2013). With more than half of all Soldiers having deployed and the average deployed Soldier spending 9.7 months in a combat zone, (Committee on the Assessment of the Readjustment Needs of Military Personnel et al., 2013) the transition to deployment and the return from deployment represents a multi-faceted source of stress for Soldiers (R. T. Smith & True, 2014; Yablonsky, Barbero, & Richardson, 2016). Studies have shown deployment to be associated with cardiovascular risk factors (Mcgraw et al., 2008) but the results of this study found that deployment lowered the odds of a hyperlipidemia diagnosis seven months later by two times for men and three times for women. The lowered odds may be due to increased physical activity levels during deployment (Lester et al., 2010) or that blood lipids are less likely to be assessed during deployment. Deployment was also found to be associated with substantial weight gain 12 months later in men. A study on physical fitness and body composition after deployment to Afghanistan found increases in weight to be associated with higher fat mass, (Sharp et al., 2008) while another study after deployment to Iraq found increases in weight to be associated with lean muscle gains (Lester et al., 2010). These studies indicate that differences in unit type and deployment locations have an impact on weight gain and possibly cardiovascular risk factors. Returning from deployment lowered odds of weight gain 12 months later, which may represent a return to previous body composition.

Although relocation and the social disruption that Soldiers experience can be challenging for both Soldiers and their families, (Burrell, 2006) relocation was negatively associated with blood pressure, possibly due to a decrease in work stress that counteracts the effect of moving stress (Lilley, 2018). Relocation may be less stressful to Soldiers than civilians due to the support that is received in the form of packing and moving a Soldier's household goods by the Army ("Relocation," n.d.). Changes in eating behaviors as a result of relocation ("The never-ending PCS," n.d.) may have a different effect, with relocation modestly raising odds of hyperlipidemia in men two months later. The raised odds of substantial weight gain in women eight months after relocation could be related to a woman's role as the primary food planner and preparer (Blake et al., 2009; Devine et al., 2009; Sobal et al., 2003) and disrupted routines affecting eating behaviors (Jastran et al., 2008).

Adding a child is a significant stressor related to role changes and the demands of childcare tasks (Liu & Umberson, 2015; Nomaguchi & Brown, 2011). The higher blood pressure after adding a child among women could be the result of a normal physiological response after childbirth, (James & Nelson-Piercy, 2004) but adding a child was also associated with higher odds of hyperlipidemia two months later in women indicating non-transient physiological changes. In men, higher odds of substantial weight gain two months later in those who added a child could be due to less time for exercise due to parenting responsibilities (Sobal et al., 2003) or changes in eating habits due to time demands of parenting (Morin, Demers, Turcotte, & Mongeau, 2013). Men who added a child also had higher odds of separation from the Army less than a year later for failure to meet body composition standards indicating the parenting role has an effect on the ability of some men to adhere to weight requirements.

Changes in rank and occupation may be positive when they lead to an increase in pay or a more desirable job, decreasing job-related stress (Dohrenwend & Dohrenwend, 1974). The positive association with blood pressure and lower odds of substantial weight gain can be explained by the majority of rank changes resulting from promotion and due to occupation change being voluntary in the Army. Soldiers who are not meeting body composition standards are ineligible for promotion or training for a new occupation, which potentially explains the lower odds of separation among Soldiers who changed rank or occupation (Headquarters, Department of the Army, 2016).

Becoming injured or ill is a significant stressful change for Soldiers (R. T. Smith & True, 2014) that threatens their ability to remain in service. Soldiers who develop a physical duty limitation and become MNR represent those who can no longer deploy and are unlikely to be able to meet physical fitness requirements (United States Army, 2016b). Becoming MNR was associated with higher blood pressure in men, raised odds of hyperlipidemia two months later in men and women, three times the odds of substantial weight gain two months later in men, and nearly two times the odds in women two months later. This range of effects could be due to decreased activity levels after injury (Cornelissen & Smart, 2013) or other comorbid conditions and indicates that Soldiers who are MNR have long lasting deleterious health effects. MNR reduced the odds of separation for failing to meet body composition standards due to the Army's procedures for medically discharging Soldiers who develop a disability during service (United States Army, 2016b).

In this study, we identified the timing of highest risk in respect to associations between stressful life changes and nutrition-related health outcomes among Soldiers. Risk of an outcome was not limited to a specific time, and as demonstrated with marriage and weight, there was a cumulative effect that varied between genders. In today's military, more than 60% of Soldiers have at least one dependent and Soldiers are far more likely to be married, have children, and have working spouses than in the past (Drummet et al., 2003; Moelker et al., 2015). These shifts in demographics require Soldiers to balance the demands of two "greedy institutions" – the family and the military – that demand a Soldiers attention (Segal, 1986). These tensions can be particularly difficult for female service members as they work to balance demands of motherhood and their military careers (Blake, Wethington, Farrell, Bisogni, & Devine, 2011; Wahl & Randall, 1996).

A greater percentage of women than men experienced relocation, had a marital transition, became medically not ready, and nearly equal numbers to men experienced rank change and adding a child. The magnitude of the associations between relocation and marriage on substantial weight gain were greater for women and were significantly different than men. Role strain in civilian women has been well-documented (Blake et al., 2009; Hobfoll, 2014). Single parents in the military are more likely to be women (Wahl & Randall, 1996) and with over half of all female Soldiers having experienced combat deployment, role strain among military women is likely to be a serious issue due to the demands of military service. Some stressful life changes, such as promotion, may carry a health advantage, but increases in responsibility and the dedication that is expected from all service members means that female Soldiers may not reap the same benefits as men who have lower societal expectations for family care and involvement than women (Devine et al., 2009; Sobal et al., 2003; Wahl & Randall, 1996).

We know of no other study that has examined these outcomes in Soldiers and only of a small number of studies examining sources of stress in a military population (McGrath, 1970; Pflanz & Sonnek, 2002). Strengths include the event history analysis, the sample size, and that outcomes and exposures were determined objectively and not self-reported. Changes in blood pressure were small and clinically insignificant. A better measure of the effect of stressful life changes on blood pressure may be a diagnosis of hypertension as a more definitive cardiovascular risk factor. Stress in this study was measured by exposure to stressors and not by perception of stress or by indicators of stress such as mental distress or blood cortisol levels. An individual's response to stressful life changes is influenced by how they appraise the stressor and the threat it poses (Tomaka et al., 1993). It is possible that Soldiers perceive stressors differently than civilians, but the results of this study show parallels between Soldiers and civilians in the physiological effects of stressful exposures.

Conclusion

In this study, we examined the relationship between stressful life changes and specific nutrition-related health outcomes among all U.S. Army Soldiers using data arranged as a person-month-based panel for up to four years of observations. There is a large body of literature demonstrating the effects of stressful changes, such as marriage on weight gain (Dinour et al., 2012) and job strain on hypertension and hyperlipidemia, (Kivimäki et al., 2002; Lagraauw et al., 2015; Matthews & Gump, 2002) but existing studies typically have data collection intervals that range in length from several months to several years (Dinour et al., 2012). This research capitalized on the Army's health surveillance system allowing for changes in outcomes or exposures to be observed in monthly intervals. The small intervals between measures allowed us to pinpoint the specific month when odds of an outcome were highest, presenting the opportunity to better understand patterns of outcome development and contributes new information about the timing of health effects associated with stressful life changes that is applicable to military and civilian populations.

With the exception of deployment, the stressful life changes that were examined are universal, but the ramifications of these occurrences such as having to deploy as a single parent or receiving a medical discharge because of being MNR are unique to Soldiers. The differences in associations and the magnitude of associations by gender show the stressful life changes in this study affect male and female Soldiers differently.

Further research into the gender specific processes influencing these differences could be a key step towards preventing the development of undesirable health outcomes in all Soldiers.

Soldiers are often young and active, but they are not free of cardiovascular risk factors or insulated from substantial weight gain. By identifying times in a Soldiers life-course when the risk of developing an undesirable health outcome is highest, this research offers a new approach for proactively addressing Soldier health. Utilizing this information could help the Army employ existing resources such as Chaplains, dietitians, mental health professionals, or resilience programs to mitigate the effects of stress on Soldier health.

Table 4.6. Characteristics of Soldiers, stratified by gender, Stanford Military Data Repository, 2011-2014.

Outcome, exposure, and sociodemographic variables, mean (SD) or %	**Men n=708,884**	**Women n=118,242**
Outcomes		
Mean systolic blood pressure	125.4(11.6)	117.1(11.3)
Diagnosis of hyperlipidemia	6.1	2.7
Substantial weight gain	22.1	39.3
Separation for failing body composition standards	0.8	0.7
Exposures		
Marital transition	19.1	26.4
Deployment to combat zone	66.8	50.5
Relocation	63.8	64.4
Added a child	26.2	21.30
Rank change	36.4	33.1
Change in Army occupation	7.4	0.04
Became Medically Not Ready (MNR)	4.3	5.1
Sociodemographics		
Age at last observation, years	29.7(8.1)	29.0(8.0)
Rank categories[a]		
E1-E3	21.4	24.0
E4	28.8	29.6
E5-E6	25.6	21.6
E7-E9	9.7	7.4
W1-W5	2.5	1.5
O1-O3	6.9	10.6
O4-O10	5.0	5.3
Time in service, years		
Less than 4	40.4	45.8
4-10	29.4	29.1
11-18	16.7	14.8
More than 18	13.5	10.3
Branch of Army		
Combat Arms	45.7	0.0
Combat Support	37.6	39.3
Combat Service Support	16.7	60.7
Marital Status		
Married	58.4	48.6
Single	36.8	38.1
Divorced/Widowed	4.8	13.3
Number of Children		
None	52.1	61.8
1-2	34.1	31.4
3 or more	13.8	6.8

[a]Enlisted ranks: E1-E9; Officer ranks: W1-O10.

Table 4.6 (Continued). Characteristics of Soldiers, stratified by gender, Stanford Military Data Repository, 2011-2014.

Outcome, exposure, and sociodemographic variables, mean (SD) or %	**Men n=708,884**	**Women n=118,242**
Level of education		
High School/GED	69.2	60.0
Some College	13.2	15.4
Bachelors	11.7	15.9
Graduate	6.0	8.7
Race/Ethnicity		
Non-Hispanic White	64.2	43.5
Non-Hispanic Black	17.6	34.7
Non-Hispanic Asian/Pacific Islander	3.6	4.6
Multi-Racial	2.2	3.3
American Indian/Alaskan Native	0.6	1.0
Hispanic	11.8	12.9

[a]Enlisted ranks: E1-E9; Officer ranks: W1-O10.

Table 4.7. Results of the regression analyses of blood pressure by stressful life changes in Soldiers, Stanford Military Data Repository, 2011-2014.

Exposure and control variables	**Men n=226,001**		**Women n=64,733**		**Difference between men and women**
	Coefficient	***p***	**Coefficient**	***p***	**z (*p*)**
Marital transition					
Becoming married	0.491	0.010	0.354	0.077	0.495 (0.620)
Deployment					
Becoming deployed	-0.128	0.274	0.398	0.055	2.208 (0.027)
Relocation					
Relocation	-1.346	< 0.001	-1.317	< 0.001	0.154 (0.878)
Adding a child					
Added a child	-0.107	0.485	2.472	< 0.001	10.085 (<0.001)
Change in rank					
Rank change	0.474	0.001	0.356	0.058	0.051 (0.613)
Change in occupation					
Change in occupation	-0.791	0.004	--	--	--
Developed physical duty limitation					
Became Medically Not Ready (MNR)	1.243	< 0.001	0.420	0.379	1.507 (0.132)
Race/Ethnicity					
NH Black	0.527	< 0.001	0.490	< 0.001	0.487 (0.626)
NH Other	-0.421	< 0.001	-0.794	< 0.001	2.963 (0.003)
Hispanic	-0.594	< 0.001	-1.031	< 0.001	4.473 (<0.001)
Education Level					
Some College	-0.127	0.012	-0.245	< 0.001	1.253 (0.210)
Bachelors	-0.465	< 0.001	-0.352	< 0.001	1.145 (0.252)
Graduate	-1.073	< 0.001	-0.972	< 0.001	0.688 (0.491)
Time in service, years					
4-10	0.780	< 0.001	0.173	< 0.001	7.651 (<0.001)
11-18	0.620	< 0.001	0.293	< 0.001	2.686 (<0.001)
More than 18	0.524	< 0.001	0.357	< 0.001	0.923 (0.356)
Age	0.066	< 0.001	0.117	< 0.001	6.561 (<0.001)
Constant	70.461	< 0.001	59.265	< 0.001	28.428 (<0.001)

Note: Referent group is Non-Hispanic (NH) White, High School/GED, <4 service years. Variance explained: 19.3% and 24.3% for men and women, respectively.

Table 4.8. Odds ratios and 95% confidence intervals from logistic regression of hyperlipidemia diagnosis by stressful life changes in Soldiers, Stanford Military Data Repository, 2011-2014.

Exposure and control variables	**Odds Ratios [95% CI]** Men n=607,396	Women n=97,910	**Difference between men and women z (*p*)**
Marital transition			
Becoming married, 3 months prior	1.081 [0.922, 1.267]	1.120 [0.700, 1.792]	0.434 (0.664)
Deployment			
Becoming deployed, 7 months prior	0.453 [0.397, 0.518]	0.266 [0.119, 0.593]	1.287 (0.198)
Return from deployment, 7 months prior	1.108 [1.015, 1.209]	1.273 [0.888, 1.824]	0.863 (0.388)
Relocation			
Relocation, 2 months prior	1.196 [1.121, 1.278]	1.127 [0.888, 1.430]	0.473 (0.636)
Adding a child			
Added a child, 2 months prior	0.953 [0.867, 1.047]	1.497 [1.109, 2.021]	2.818 (0.005)
Change in rank			
Rank change, 2 months prior	0.941 [0.816, 1.085]	0.719 [0.416, 1.241]	0.933 (0.351)
Change in occupation			
Change in occupation, 1 month prior	1.127 [0.942, 1.348]	--	--
Developed physical duty limitation			
Became MNR, 2 months prior	1.417 [1.145, 1.753]	1.827 [1.007, 3.316]	0.787 (0.431)
Race/Ethnicity			
NH Black	0.993 [0.964, 1.022]	0.848 [0.771, 0.933]	3.095 (0.002)
NH Other	1.252 [1.203, 1.303]	0.951 [0.825, 1.095]	3.660 (0.0003)
Hispanic	1.199 [1.157, 1.242]	0.977 [0.849, 1.123]	2.811 (0.005)
Education Level			
Some College	1.022 [0.992, 1.054]	0.921 [0.821, 1.034]	1.708 (0.088)
Bachelors	0.981 [0.949, 1.013]	0.904 [0.806, 1.014]	1.328 (0.184)
Graduate	0.873 [0.841, 0.906]	0.756 [0.662, 0.864]	2.035 (0.042)
Time in service, years			
4-10	1.597 [1.520, 1.677]	1.155 [0.999, 1.335]	4.146 (<0.001)
11-18	2.046 [1.943, 2.154]	1.414 [1.220, 1.639]	4.631 (<0.001)
More than 18	2.536 [2.383, 2.699]	1.662 [1.391, 1.985]	4.395 (<0.001)
Age	1.105 [1.102, 1.107]	1.110 [1.102, 1.118]	1.372 (0.170)
Constant	0.0000335 [0.0000312, 0.0000359]	0.0000335 [0.0000312, 0.0000359]	<0.001 (0.999997)

Note: Medically Not Ready (MNR); Referent group is Non-Hispanic (NH) White, High School/GED, <4 service years. Area under the receiver operating characteristic (ROC) curve statistic: 0.80 men, 0.77 women.

Table 4.9. Odds ratios and 95% confidence intervals from logistic regression of substantial weight gain by stressful life changes in Soldiers, Stanford Military Data Repository, 2011-2014.

Exposure and control variables	**Odds Ratios [95% CI]** **Men** **n=541,782**	**Women** **n=74,513**	**Difference between men and women** **z (*p*)**
Marital transition			
Becoming married, 3 months prior	1.235 [1.155, 1.320]	1.683 [1.506, 1.890]	4.705 (<0.001)
Becoming single, 3 months prior	1.076 [0.934, 1.240]	0.804 [0.660, 0.981]	0.129 (0.898)
Deployment			
Becoming deployed, 12 months prior	1.189 [1.145, 1.236]	0.982 [0.884, 1.090]	3.340 (<0.001)
Return from deployment, 12 months prior	0.912 [0.873, 0.952]	0.957 [0.865, 1.059]	1.798 (0.072)
Relocation			
Relocation, 8 months prior	0.904 [0.873, 0.936]	1.156 [1.089, 1.228]	6.966 (<0.001)
Adding a child			
Added a child, 8 months prior	1.061 [1.001, 1.118]	--	--
Change in rank			
Rank change, 8 months prior	0.945 [0.906, 0.986]	0.992 [0.905, 1.088]	0.955 (<0.001)
Change in occupation			
Change in occupation, 11 months prior	0.934 [0.846, 1.031]	--	--
Developed physical duty limitation			
Became MNR, 2 months prior	3.156 [2.894, 3.441]	1.685 [1.363, 2.082]	5.379 (<0.001)
Race/Ethnicity			
NH Black	1.032 [1.016, 1.047]	1.128 [1.097, 1.160]	5.517 (<0.001)
NH Other	0.927 [0.905, 0.949]	0.944 [0.903, 0.987]	0.718 (0.473)
Hispanic	1.024 [1.001, 1.042]	0.970 [0.933, 1.001]	2.524 (0.012)
Education Level			
Some College	0.854 [0.839, 0.869]	0.889 [0.857, 0.919]	1.967 (0.049)
Bachelors	0.573 [0.562, 0.585]	0.728 [0.703, 0.754]	11.575 (<0.001)
Graduate	0.495 [0.479, 0.511]	0.730 [0.694, 0.768]	12.551 (<0.001)
Time in service, years			
4-10	0.773 [0.761, 0.784]	0.793 [0.769, 0.818]	1.500 (0.134)
11-18	0.623 [0.609, 0.637]	0.725 [0.693, 0.758]	5.924 (<0.001)
More than 18	0.749 [0.725, 0.775]	0.731 [0.684, 0.782]	0.638 (0.523)
Age	0.982 [0.980, 0.983]	0.982 [0.979, 0.985]	0.246 (0.806)
Constant	0.0244 [0.0235, 0.0253]	0.0375 [0.0349, 0.0402]	32.622 (<0.001)

Note: Medically Not Ready (MNR); Referent group is Non-Hispanic (NH) White, High School/GED, <4 service years. Area under the receiver operating characteristic (ROC) curve statistic: 0.62 men, 0.60 women.

Table 4.10. Odds ratios and 95% confidence intervals from logistic regression of separation for failing to meet body composition standards by stressful life changes in Soldiers, Stanford Military Data Repository, 2011-2014.

Exposure and control variables	**Odds Ratios [95% CI]**		**Difference between men and women**
	Men n=422,716	**Women n=61,289**	**z (*p*)**
Marital transition			
Becoming married, 10-21 months prior	1.041 [0.900, 1.203]	0.934 [0.667, 1.309]	0.581 (0.561)
Deployment			
Becoming deployed, 13-24 months prior	0.840 [0.763, 0.925]	0.908 [0.694, 1.189]	0.538 (0.591)
Relocation			
Relocation, 13-24 months prior	1.059 [0.971, 1.154]	1.253 [0.988, 1.535]	1.250 (0.211)
Adding a child			
Added a child, 1-12 months prior	1.225 [1.098, 1.368]	1.114 [0.794, 1.563]	0.528 (0.598)
Change in rank			
Rank change, 4-15 months prior	0.335 [0.297, 0.378]	0.316 [0.232, 0.432]	0.342 (0.732)
Change in occupation			
Change in occupation, 10-21 months prior	0.620 [0.439, 0.876]	--	--
Developed physical duty limitation			
Became MNR, 10-21 months prior	0.206 [0.077, 0.548]	0.247 [0.035, 1.741]	0.163 (0.871)
Race/Ethnicity			
NH Black	0.597 [0.526, 0.677]	0.729 [0.572, 0.928]	1.428 (0.153)
NH Other	0.696 [0.571, 0.848]	0.989 [1.690, 1.417]	1.618 (0.106)
Hispanic	1.005 [0.896, 1.126]	0.628 [0.444, 0.887]	2.529 (0.011)
Education Level			
Some College	0.423 [0.360, 0.496]	0.326 [0.227, 0.469]	1.280 (0.201)
Bachelors	0.104 [0.079, 0.137]	0.121 [0.074, 0.198]	0.500 (0.617)
Graduate	0.038 [0.016, 0.092]	--	--
Time in service, years			
4-10	0.635 [0.573, 0.704]	0.679 [0.533, 0.865]	0.493 (0.622)
11-18	0.366 [0.310, 0.431]	0.645 [0.429, 0.968]	2.536 (0.011)
More than 18	0.039 [0.022, 0.069]	0.046 [0.006, 0.365]	2.013 (0.044)
Age	0.972 [0.960, 0.983]	0.970 [0.942, 0.999]	0.101 (0.920)
Constant	0.00238 [0.00176, 0.00322]	0.00278 [0.00131, 0.00589]	0.3732 (0.709)

Note: Medically Not Ready (MNR); Referent group is Non-Hispanic (NH) White, High School/GED, <4 service years. Area under the receiver operating characteristic (ROC) curve statistic: 0.77 men, 0.76 women.

Figure 4.6. Cumulative probability over 12 subsequent months of substantial weight gain in Soldiers who did or did not get married, Stanford Military Data Repository, 2011-2014.

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CHAPTER 5

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

5.1 Summary of Major Findings

The obesity epidemic represents a serious threat to the ability of the military to bring in recruits that are able to meet the physical fitness and weight management requirements of the Army (Cawley & Maclean, 2012). Substantial weight gain can cause Soldiers to be out of compliance with body composition standards or put them closer to exceeding weight and body composition standards in the future. Hypertension and hyperlipidemia increase the risk of cardiovascular disease which threatens the ability of Soldiers to perform their duties and meet mission requirements (Mcgraw et al., 2008). Influencing the development of undesirable health outcomes in Soldiers is the stressful environment that characterizes military service, which must be balanced with stressful life changes that normally occur over an individual's life-course.

BMI as an anthropometric tool has been essential for describing the obesity epidemic and its effects on health (Flegal et al., 2012). The ability to track BMI trends in populations is aided by the identification of common BMI trajectories in a population. Establishing the BMI trajectories of a population also enables the examination of characteristics or determinants that influence trajectory membership. This research addressed the lack of identified BMI trajectories in U.S. Army Soldiers and found that the overall trajectory of Soldiers differs from that of civilians, which is likely a result of factors related to Army service. It appears that Soldiers who stay in the Army long-term have a lower peak BMI than civilians and that overall, BMI in Soldiers begins to decline sooner than in civilians. Understandably, much of the discourse on the BMI of Soldiers is centered on obesity, but this research showed BMI trends with aging that could be beneficial for career Soldiers considering the health benefits of a lower BMI for a significant portion of their adult lives.

This research found four distinct BMI trajectories among Soldiers: increasing, decreasing, constant, and inconstant. The constant, increasing, and decreasing trajectories were similar in shape and percentage distribution between men and women, but the inconstant trajectory differed in shape between genders. It was found that over 6% of men and 12% of women had fluctuations in BMI indicative of weight cycling. Weight cycling can indicate employment of extreme weight loss strategies and studies have shown weight cycling to be predictive of future weight gain (Kroke et al., 2002; Saarni et al., 2006).

Bivariate associations revealed differences in the Soldier characteristics that influenced trajectory membership. Sixty percent of Soldiers were in the constant trajectory – which had the lowest percentage of Soldiers who were MNR, exceeded weight standards, and had BMI fluctuations indicative of weight cycling. When combined with the decreasing trajectory group, these results indicate that 67% of men and women in the Army were able to self-monitor their weight and maintain a BMI that keeps them within Army standards. The military represents the largest known population consistently self-monitoring weight, thus adding to the evidence of self-monitoring as an effective weight management strategy.

Even though the majority of Soldiers were able to self-manage their weight within Army standards, the percent of Soldiers in the increasing and inconstant trajectories indicate that over 30% of Soldiers had issues with weight management. From a health standpoint, the increasing and constant trajectories appear to be the most concerning to the Army because in both genders, they had the highest percentage of Soldiers who were MNR, exceeded weight standards, and had BMI fluctuations indicative of weight cycling compared to the constant or decreasing trajectory groups. When all male and female Soldiers in the increasing and inconstant trajectories are combined, a large number of Soldiers (n=214,341) falls into the increasing and constant trajectories, demonstrating the urgent need to better understand the determinants of trajectory membership.

Results from the event history analysis that examined associations between stressful life changes and nutrition-related health outcomes showed that stressful life changes are associated with earlier onset of undesirable health outcomes such as hyperlipidemia and substantial weight gain. A unique feature of these data were the small intervals between observations, which enabled the month when the odds were highest of developing a study outcome to be pinpointed – but findings also revealed that that odds of an outcome were consistently higher after exposure to a stressful life change. To help identify the month with the highest odds, coefficients from preliminary models of all months during the proposed risk period were plotted to help visually identify the time when estimates showed the greatest effect. In these graphs, the odds of an outcome rarely dropped dramatically, indicating that the odds of an outcome were elevated for months after the stressful life change. For example, it was identified that risk of substantial weight gain was highest three months after marriage, but four months after marriage the risk was only slightly lower. These relatively flat curves indicated that stressful life changes have lasting effects and that there is a relatively broad window of time in which interventions could be employed that may reduce the effects of stress on health.

There is also a cumulative effect of stressful life changes on health, as indicated in the analysis of the probability of weight gain in the 12 months after marriage. This analysis showed that the probability of event occurrence after a stressful life change is additive over time. The risk at any given month underestimates the cumulative risk to a Soldier's health after experiencing a stressful life change. In figure 4.6, the probability of substantial weight gain increased for Soldiers who married and those who did not. The magnitude of the difference in weight gain between those who married and those that did not widened after 12 months and the difference was even greater for women than men. This finding highlights the accumulation of risk of substantial weight gain after exposure to the stressful life change of marriage and that the likelihood of developing a nutrition-related health outcome increases incrementally and steadily.

Results of both analyses revealed gender differences in the characteristics associated with BMI trajectories and the stressful life changes associated with nutrition-related health outcomes. For men, increasing age and service years were related to lower risk of increasing trajectory membership, but for women, increasing age and service years were related to higher risk of increasing trajectory membership. Across all trajectory groups, a higher percentage of women than men were MNR or exceeded weight gain. In the analysis of stressful life changes, more women than men experienced relocation, had a marital transition, or became MNR; with nearly equal numbers of both genders who experienced rank change or added a child. The associations between marriage and substantial weight gain in women were greater and significantly different from men, and women had greater cumulative probability of weight gain in the 12 months following marriage than men. It is likely that role strain is an issue for military women (Wahl & Randall, 1996). Similarly to civilian women, female Soldiers shoulder the majority of domestic responsibilities (Wahl & Randall, 1996), and must balance family demands with the demands of military service. Gender differences in expectations and workload related to family care may help to explain the differences in the characteristics influencing BMI trajectory membership and nutrition-related health outcomes between men and women. Considering that women comprise nearly 15% of Soldiers and that over one-third have children, it is imperative to better understand how gendered roles and responsibilities may influence the health of female Soldiers.

5.2 Implications

In this document, the term “readiness” is used to describe the preparedness of a Soldier for combat or in the case of medical readiness, to describe a Soldier being in a state of health that does not hinder the Soldier from being fully mission capable (“Readiness,” n.d.). One of the goals of Army medicine is to improve Soldier readiness (*Army Medicine Campaign Plan*, 2017) which is threatened by a reduced pool of physically fit young men and women to recruit from and by the development of undesirable health outcomes during a Soldier’s career.

The 2017 Army Medicine Campaign Plan (the strategic document that outlines the ways in which the Army envisions meeting its organizational objectives) identified that a key process in meeting objectives was to “Improve Healthy Behaviors, Communities and Environments"(*Army Medicine Campaign Plan*, 2017). A key method identified under this objective was to move to a "predict and prevent" model that would work in partnership with the individual Soldier to improve health (*Army Medicine Campaign Plan*, 2017). In 2015, the Army began to train health professionals and commanders to use an innovative system called the Medical Readiness Assessment Tool (MRAT), which uses a Soldier's individual health data to identify those at higher risk for undesirable health outcomes that threaten readiness ("Medical Readiness Assessment Tool (MRAT)," n.d.). Developed by Dr. D. Alan Nelson and others, the MRAT utilizes the same data sources that were used in this research to identify Soldiers whose BMI or history of injury (among numerous other predictors) puts them at increased risk for becoming MNR ("Medical Readiness Assessment Tool (MRAT)," n.d.). The methods that drive the MRAT were based on published studies on predicting readiness outcomes among soldiers (A. D. Nelson & Kurina, 2013; D. A. Nelson, Wolcott, & Kurina, 2016). The MRAT has shown promise for interventions that prevent musculoskeletal injuries ("Latest Army medical innovation to keep soldiers ready for the fight," 2016), but there is no equivalent tool in the military health system for other health outcomes (such as cardiovascular disease) or a mechanism for identifying when Soldiers have experienced stressful life changes.

A tenet of Army leadership is to care for the well-being of Soldiers (Department of Defense, 2017). The Army recognized that stressful life changes, among other concerns, can distract Soldiers from the mission, thus the Army has made efforts to provide greater instrumental support to Soldiers and their families ("Army Family Covenant," n.d.). Soldiers belong to a complex organizational structure ("Military Units:

How Each Service Is Organized | DoDLive," n.d.) in which commanders are reliant on lower levels of leadership to know their Soldiers and be aware what is going on in their lives. In many cases, leadership may know about the stressful life changes Soldiers are experiencing because they may request leave or need time off for medical appointments. In other cases, such as when a Soldier relocates and is assigned to a new unit, leadership has no mechanism to know about the stressful life changes a Soldier has experienced. This research established that stressful life changes do have an effect on Soldiers' health. Similarly to or in conjunction with the MRAT, the Army could use information on stressful life changes to help identify Soldiers who have had stressful exposures and employ existing resources to mitigate the risk of developing undesirable health outcomes. Expanding the capabilities of the MRAT to identify Soldiers who have experienced stressful life changes could enhance the applicability of the MRAT by furthering its usefulness in identifying those at higher risk for undesirable health outcomes that are related to stressful exposures.

The Army has resources and existing programs specifically aimed to improve the ability of Soldiers to adjust and adapt (Casey, 2011). The Comprehensive Soldier and Family Fitness (CSF2) program mandated resilience training to all Soldiers, with the primary aim of enhancing Soldiers' "psychological strength" (Casey, 2011; *Comprehensive Soldier and Family Fitness*, 2014). Evaluation of the CSF2 program showed reduced odds of mental health diagnosis for those who received resilience training (Harms, Herian, Krasikova, Vanhone, & Lester, 2013). A further step in proactively addressing Soldier health could be to use the MRAT to identify Soldiers who have recently experienced stressful life changes and then employ proven resources at critical transitions in a Soldier's life-course to help the Soldier adjust and adapt to the consequences of stressful life changes.

Soldiers are often young and active, but as shown by this research and previous studies, they are not free of cardiovascular risk factors nor are they insulated from substantial weight gain that threaten readiness. The Army represents the largest known population that consistently self-monitors weight, and – as indicated by the over 60% of Soldiers with a constant or declining BMI trajectory – this appears to be effective for the majority of individuals. The Army's mandatory bi-annual weight and body composition checks and the inconvenient and career-threatening ramifications when Soldiers do not comply with weight standards are reinforcing factors in a Soldier's motivation to self-monitor and self-manage weight ("Overweight," n.d.; United States Army, 2013). Even with standards for physical fitness and body composition, over 30% of Soldiers were in a BMI trajectory group that had a high percentage of individuals who exceeded weight standards. A possible way to leverage existing processes that promote and reinforce weight self-monitoring is to increase the frequency of annual mandatory weight assessments, which may help motivate Soldiers to maintain a weight that complies with regulations and minimizes weight fluctuations.

5.3 Strengths and Limitations

This research relied upon BMI to describe weight trends among Soldiers. BMI is useful to predict chronic disease risk and relative weight in populations, but use of BMI may result in misclassification of individuals as overweight or obese especially in populations with higher muscularity, such as Soldiers (Flegal et al., 2009, 2012). Although BMI is not a direct measure of body composition, previous studies on methods of assessing obesity found BMI to be a "statistically equivalent" method of predicting percent body fat in an active duty military population (Heinrich et al., 2008). This research did not use BMI to classify Soldiers as overweight or obese; but the increasing BMI trajectory had the largest percentage of Soldiers who exceeded Army weight standards and the Soldiers with highest mean BMI, which indicates this trajectory group did capture Soldiers for whom overweight or obesity is more likely. The data contained some body fat measures that were taken during mandatory body composition checks, but the lack of consistent data entry into the database from which data were drawn precluded the use of body fat in this research.

Self-selection bias may influence BMI trends, particularly when analyzing BMI changes associated with aging. Soldiers who are more successful at weight management are less likely to suffer the punitive consequences of violating Army body composition standards and may choose to stay in the Army longer than those who have greater difficulty self-managing weight. It is possible that the ability to meet body composition standards may influence the decision to stay in the Army beyond initial obligations, but that ability was not listed as one of the top five reasons enlisted service members leave the military (United States General Accounting Office, 2001). About 6,000 Soldiers were involuntarily discharged from service in the four years that were studied, representing less than 1% of the total study population. This figure suggests that body composition failure is not a main cause of involuntary separation; although the ability to meet body composition standards may play a role in voluntary separation and therefore BMI trends, considering that older Soldiers are usually career Soldiers.

To answer the research questions, a large longitudinal dataset was used, but the analysis was limited to four years of observations. This was not a hindrance to answering the research questions, but being able to draw upon more years of BMI observations could have added additional information to the BMI trajectories; such as if the high operational tempo due to the Army being engaged in two wars during the study period affected BMI trends, and if BMI trends differ during periods of relative peace.

More years of observations could have also added information about the accumulation of stressful life changes over a Soldier's life course, particularly in career Soldiers. While specific stressful life changes affect health outcomes, it is possible that the number of stressful life changes Soldiers experience over their careers also contribute to the timing and development of undesirable health outcomes. Additional years of observations could enable a more nuanced investigation into the longer-term effects of stress on Soldier health.

Using change in blood pressure to assess the physiological effects of stressful life changes may not have been the ideal way to investigate this outcome considering the labile nature of blood pressure. It is not just spikes in blood pressure that pose a health threat, but repeated spikes or prolonged elevations that weaken the body's ability to return to homeostasis (Logan & Barksdale, 2008). Changes in blood pressure may not have been detected if blood pressure was consistently elevated (Black & Garbutt, 2002; Mustacchi, 1990) around the time the stressful life change occurred and when blood pressures was measured. Another way to measure the effect of stressful life changes on blood pressure could be a diagnosis of hypertension as a more definitive cardiovascular risk factor. An average of blood pressure measurements over a longer period of time could also be used to ensure blood pressure measures reflect the period of time before a stressful life change begins, since some life changes – such as relocation – can be prolonged occurrences. This research did not find clinically significant changes in blood pressure that coincided with occurrences of stressful life changes, but the established association between stress and hypertension (Black & Garbutt, 2002) suggests that reexamining the way in which blood pressure changes were defined for this research may be warranted in future studies.

Stress in this study was measured by exposure to stressors and not by perception of stress or by indicators of stress such as mental distress or blood cortisol levels. An individual's response to stressful life changes is influenced by how they appraise the stressor and the threat it poses (Tomaka et al., 1993). It is possible that Soldiers perceive stressors differently than civilians, but the results of this study show parallels between Soldiers and civilians in the physiological effects of stressful exposures. Even though this research does not account for an individual's perception of a stressor, a large body of research has used life experiences as a proxy for stress (Keyes, Hatzenbuehler, & Hasin, 2011; Kingston, Heaman, Fell, Dzakpasu, & Chalmers, 2012) and have demonstrated the undesirable effects of stressful life changes on health (Hammen, 2005; Lagraauw et al., 2015; Liu & Umberson, 2015).

5.4 Future research

There are many avenues of future research that could stem from this study. The BMI trajectories established here could be used to identify changes in BMI patterns over time and additional Soldier characteristics could be investigated as determinants of BMI trajectory. An original aim of this study was to investigate if stressful life changes were associated with BMI trajectories. Time did not allow for that analysis to be completed for this dissertation, but it is this author's objective to continue this line of research and examine associations between stressful life changes and BMI trajectory membership.

Other research opportunities include examining how the psychological and behavioral paths outlined in the conceptual model of this research mediate nutrition-related health outcomes. Mental health conditions threaten readiness and contribute to poor quality of life among Soldiers ("Depression impacts readiness," n.d.). Not only do Soldiers suffer from depression, but female Soldiers are more at risk than male Soldiers (Wells et al., 2010).

Gender differences were found in the results of both analyses of this research. Gender differences in roles and responsibilities between men and women can lead to role strain in women (Wahl & Randall, 1996) and reduce the health benefits of life-course occurrences, such as promotion and marriage. Further research into the gender-specific processes influencing these differences could be a key step towards preventing the development of undesirable health outcomes in all Soldiers.

This research also prompts the question of what interventions would be most effective and when should they be employed to mitigate the effects of stress on health? This research identified that stressful life changes have an effect on health, when the occurrence of a stressful life change posed the highest risk of outcome development, and that risk to health is cumulative, but it does not answer the question of how the Army should intervene. The Army has multiple programs and resources such as the CSF2 program, chaplains, mental health professions, and dietitians, but which ones would be most effective? After what stressful life changes and when? These are all areas of future research that could help the Army better target resources aimed at improving Soldier health.

In summary, this research addressed gaps in the literature related to pertinent outcomes that affect the readiness of Soldiers. This study established the overall and most common BMI trajectories of Soldiers, and contributed new information regarding the timing of nutrition-related health outcomes after stressful life changes that is applicable to both military and civilian populations. The implications of this research suggests that new proactive approaches could be used to help identify Soldiers who are at higher risk for developing undesirable health outcomes. This research also identified areas of future research that could guide the use of existing resources aimed at improving the health of Soldiers.

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APPENDIX A - HEIGHT/WEIGHT SCREENING TABLE FROM ARMY REGULATION 600-9

Table A.1. Height/Weight Screening Table from Army Regulation 600-9.

Table B–1
Weight for height table (screening table weight)

		Male weight in pounds, by age				Female weight in pounds, by age			
Height (inches)	Minimum weight[1] (pounds)	17–20	21–27	28–39	40+	17–20	21–27	28–39	40+
58	91	-	-	-	-	119	121	122	124
59	94	-	-	-	-	124	125	126	128
60	97	132	136	139	141	128	129	131	133
61	100	136	140	144	146	132	134	135	137
62	104	141	144	148	150	136	138	140	142
63	107	145	149	153	155	141	143	144	146
64	110	150	154	158	160	145	147	149	151
65	114	155	159	163	165	150	152	154	156
66	117	160	163	168	170	155	156	158	161
67	121	165	169	174	176	159	161	163	166
68	125	170	174	179	181	164	166	168	171
69	128	175	179	184	186	169	171	173	176
70	132	180	185	189	192	174	176	178	181
71	136	185	189	194	197	179	181	183	186
72	140	190	195	200	203	184	186	188	191
73	144	195	200	205	208	189	191	194	197
74	148	201	206	211	214	194	197	199	202
75	152	206	212	217	220	200	202	204	208
76	156	212	217	223	226	205	207	210	213
77	160	218	223	229	232	210	213	215	219
78	164	223	229	235	238	216	218	221	225
79	168	229	235	241	244	221	224	227	230
80[2]	173	234	240	247	250	227	230	233	236

Notes:
[1] Male and female Soldiers who fall below the minimum weights shown in table B–1 will be referred by the commander for immediate medical evaluation.
[2] Add 6 pounds per inch for males over 80 inches and 5 pounds per inch for females over 80 inches.

APPENDIX B - MAXIMUM ALLOWABLE PERCENT BODY FAT FROM ARMY REGULATION 600-9

Table B.1. Maximum Allowable Percent Body Fat from Army Regulation 600-9.

Table B–2
Maximum allowable percent body fat standards

Age group	Male (% body fat)	Female (% body fat)
17–20	20%	30%
21–27	22%	32%
28–39	24%	34%
40 and older	26%	36%